ALPHA AND OMEGA

An Informal History of the Defence Research Establishment Pacific 1948-1995

edited by

R. P. Chapman

Defence Research Establishment Atlantic
Dartmouth, Nova Scotia
1998

ISBN 0-660-17445-6
Cat. no. D2-116/1995E

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Defence Research Establishment Atlantic
P.O. Box 1012
9 Grove Street
Dartmouth NS
B2Y 3Z7

Document printed and bound by FLEMING EXPRESS PRESS LTD, Victoria, BC

102-03527/

CONTENTS

FOREWORD *T. Garret* v

ACKNOWLEDGEMENT vii

OVERVIEW *R.P. Chapman* ix

1. DEFENCE RESEARCH ON THE WEST COAST *R.P. Chapman* 1

- ***Budget '94*** 1
- ***1936 to 1945 - pre-war and wartime*** 1
- ***1946 to 1948 - early post-war - the beginnings of DRB and PNL*** 2
- ***1948 to 1953 - the formative years*** 3
- ***1954 to 1955 - the new building*** 13
- ***1956 to 1959 - PNL - research ships replaced - increased interest in Arctic*** 19
- ***1960 to 1966 - a purpose built research ship - electromagnetics goes global*** 31
- ***1967 to 1969 - PNL becomes DREP - a north wing added to Building 199*** 47
- ***1970 to 1978 - increases in acoustics and materials - DRB becomes CRAD*** 56
- ***1979 to 1980 - interest develops in mine countermeasures and Arctic Basin surveillance*** 78
- ***1981 to 1985 - final experiments in fluid dynamics - increased activity in air related projects*** 84
- ***1986 to 1995 - SPINNAKER - the Gulf War - closure*** 100

2. ARCTIC UNDER-ICE ACOUSTICS *A.R. Milne* 141

- ***Background*** 141
- ***Barrow Strait, April 1959, 'Paclabar'*** 143
- ***Prince Gustaf Adolph Sea, April/May 1961, 'Icepack 1'*** 149
- ***M'Clure Strait, August/September 1961, 'Icepack 2'*** 156
- ***Arctic Ocean, April/May 1962, 'Polarpack 1'*** 160
- ***Prince Gustaf Adolph Sea, February 1963, 'Icepack 3'*** 167
- ***Prince Regent Inlet, August 1963, ' Icepack 4'*** 171
- ***Prince Gustaf Adolph Sea, January/February 1964, 'Icepack 5'*** 174
- ***Viscount Melville Sound, September 1964, 'Icepack 6'*** 178

Barrow Strait, January and April, 1965, 'Icepack 7' 180

Arctic Ocean, April 1965, 'Polarpack 2' 182

Beaufort Sea, August 1965, 'Polarpack 3' 184

M'Clure Strait, April 1966, 'Icepack 4/66' 188

Installing RIPs, August/September 1967, 'Icepack 8/67' 191

Viscount Melville Sound, April 1968, 'Icepack 4/68' 196

Recovering RIPs, August/September 1968, 'Icepack 8/68' 197

M'Clure Strait and Melville Island, 'Icepack 4/69' 205

Ice-drift in Parry Channel, 'Icepack 4/70' 208

3. FLUID DYNAMICS *H.L. GRANT & B.A. HUGES* 211

Turbulence 211

Internal Waves 222

Remote Sensing 229

4. MATERIALS TECHNOLOGY *B.F. PETERS* 237

5. EPILOGUE *R.P. CHAPMAN* 257

MAPS 261

ORGANIZATION AND PERSONNEL 267

ACRONYMS 277

INDEX 281

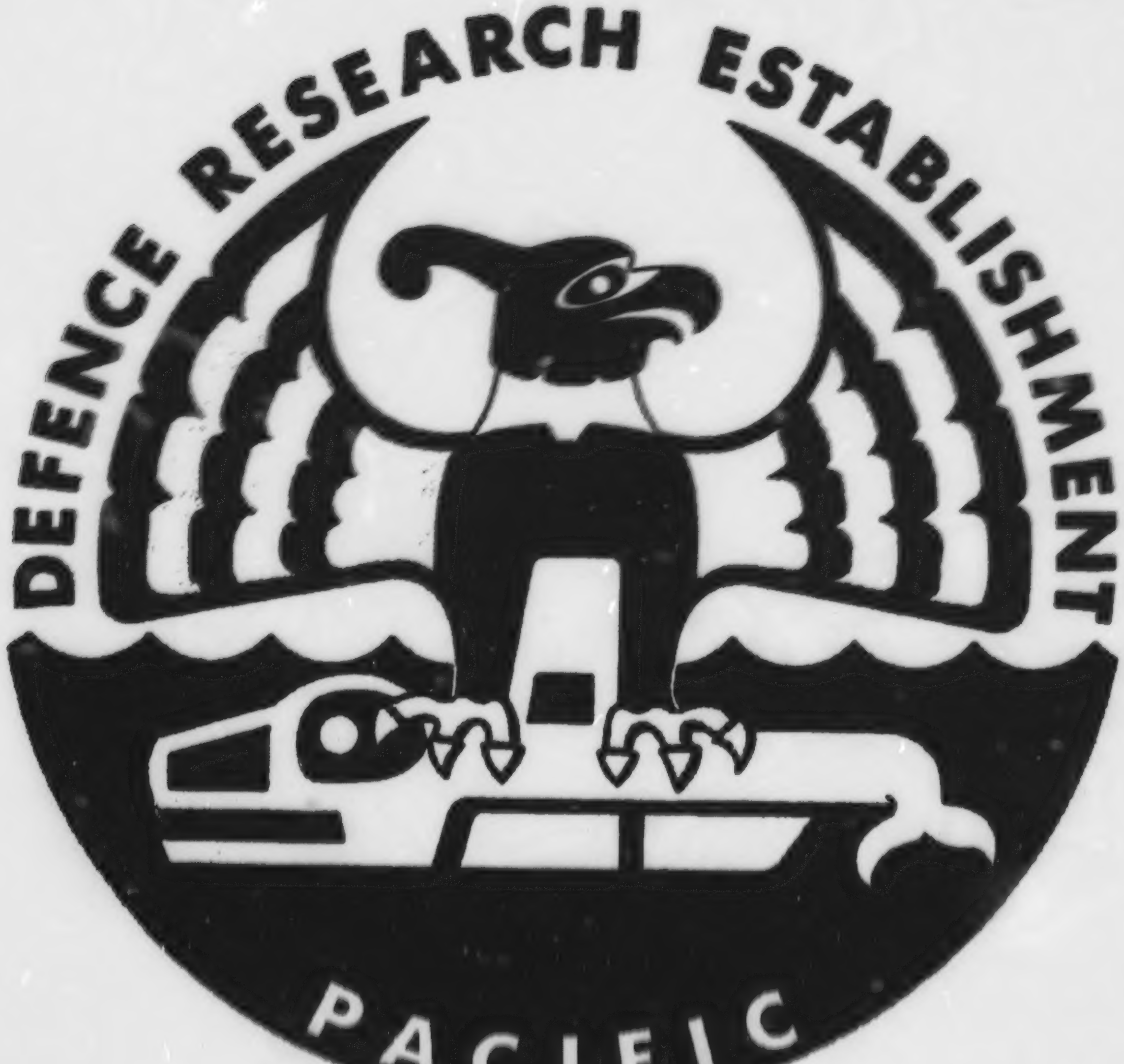
FOREWORD

It's a privilege for me to write the foreword to this history of DREP and PNL. To have associated with the dedicated and ingenious staff at DREP and their many accomplishments was the highlight in my career. As the success of an establishment depends on the quality of its people, DREP was indeed fortunate. It had a history of attracting highly competent staff, who moved the state of science forward with impressive results. Many of staff were invested into learned societies and were sought out by others around the world for co-operative research and special lectures. The security concerns of allied countries of dealing with foreign nationals were often eased to obtain the expertise that DREP staff had developed on relatively limited resources. Of course this co-operation was a two way street. In turn DREP received valuable information, the use of facilities and equipment (sometimes operational) and much important co-operation that facilitated the progress of our defence science.

Over the years DREP provided the science to maintain the CF's present and future operational capability in several areas described in this history. In doing this the staff forged major links with CF units, universities, private industry and the defence research establishments of Canada's allies. The close working relationship with the CF ensured that the scientists understood and had current knowledge of CF requirements and it allowed the CF to be up to date on the progress of the science to meet their needs and to inject knowledgeable operational input. In the latter third of DREP's illustrious existence contracting out to industry and universities became a major source of progress in meeting the needs of the CF. Highly productive working relationships were developed with research and development entities locally in Victoria and Vancouver and elsewhere in Canada. Several very effective pieces of equipment were developed and marketed that met Canadian and foreign defence needs. In addition, in a number of areas the technology developed turned out to be commercially exploitable by industry both in the domestic and foreign markets. Thus the closing of the Laboratory will undoubtedly be felt by a number of companies, particularly those in the local area which have tailored their expertise to support the DREP research program.

This history documents the many successes of a small group of spirited and adept staff who over many years applied themselves with skill and good judgement in meeting the needs of the CF and in so doing advancing the state of knowledge in Canada and the world. Following the closure of DREP, most of the personnel stayed in Canada and those who are still in the workforce are applying their abilities to other pursuits. I am sure that they are shining stars in their new endeavours.

T. Garrett
C/DREP (1986-1995)



The original PNL\DREP crest designed by Allen Milne. It was replaced in 1980 by the officially approved crest – produced by the artist Richard Hunt.

ACKNOWLEDGEMENTS

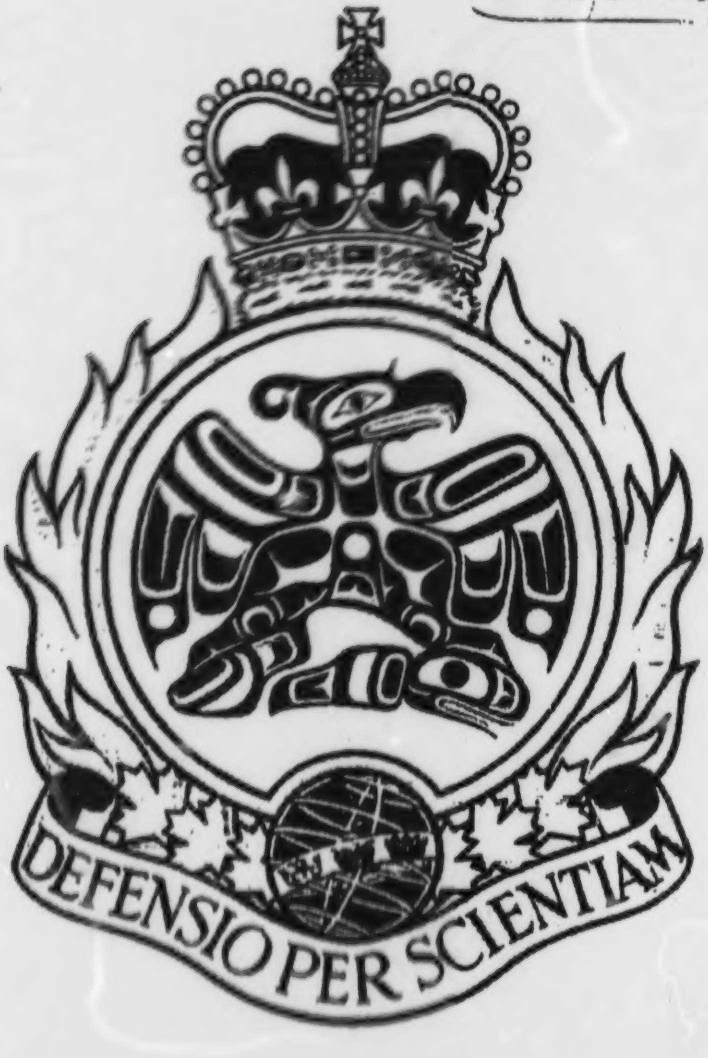
With the closing of the Defence Research Establishment Pacific in April 1995, it appeared essential to record the Establishment's principal activities and achievements before the dispersal of personnel and documentation rendered this impossible. Prompted by Ken Street, the Director of the Esquimalt Defence Research Detachment—the repository of those programs and staff that had survived the first stage of this effort in downsizing—the possibility of carrying out such a task was discussed with a number of retirees living in the area. Harold Grant, Blyth Hughes, Frank Peters, and Al Milne were most supportive and volunteered to write chapters on their respective areas of expertise. Bob Chappell was also enthusiastic and generously supplied the expertise in computers and desk-top publishing required to bring the project to fruition. Much credit is owed to Al Tregear for the extensive and well documented photographic collection which he had assembled at DREP and to the late Fred Sanders, the Laboratory's first Superintendent, and the late Captain Robin MacDonald, skipper of the CNAV LAYMORE, for their memoranda on *The Pacific Naval Laboratory—its origin and history*, and *Canadian Naval Oceanographic Research Vessels* respectively. Photographs and other background material were also graciously provided by Bob Weir from his extensive collection of PNL memorabilia.

I would particularly like to thank the staff of EDRD for their generous assistance. Although it is not possible to name them and their contributions individually, I must commend Jim Kennedy for his helpful comments on the various drafts and Wendy Don and Linda Churcher for their assistance in computer operation and the production of illustrations at a time when the entire staff was under extreme pressure from the recent downsizing.

R.P. Chapman

Approved

Elizabeth R



Defence Research Establishment Pacific

National Defence Headquarters Buckingham
September, 1980 Director of Ceremonial

OVERVIEW

During World War II, a number of facilities had been developed and operated by the Armed Forces or the National Research Council to look after the research requirements of the Canadian military. After the war, however, many of the buildings had fallen into disrepair and NRC had expressed its intention to withdraw from classified research. This resulted in an examination of how best to conduct defence research in Canada in peacetime. It was concluded that the needs of DND and the operational forces could best be met by a more centralized, civilian-managed organization. This decision was implemented in April 1947, with the creation of the Defence Research Board under the direction of Dr Omand Solandt. One of its early actions was to create a Laboratory on the West Coast to conduct research on behalf of the maritime forces. It opened in Esquimalt in mid-1948 as the Pacific Naval Laboratory (PNL) with Dr Fred Sanders its first Superintendent.

Under the impetus of the Cold War, the staff grew from an original four to reach a plateau of over one hundred and thirty between 1978 and 1985. With the collapse of the USSR in 1989, interest in defence research in DND tapered off and by the time the Laboratory closed in April 1995, the number had dropped to one hundred and twenty.

Initially, the staff operated from temporary, wartime accommodations in HMC DOCKYARD, Esquimalt. However, in October 1954, a new laboratory building was constructed on the Base to house the fifty employees then on strength. As a result of severe crowding arising from the later increases in staff, additions were continually being made to the building up until 1987.

The Laboratory was particularly fortunate in its recruiting,[1] which contributed significantly to its ability to handle a much larger research program than its size would indicate. Another feature that permitted the prosecution of large-scale projects was the extensive use of leverage. Willing and extensive support was supplied by other branches of DND, other Government Departments and external agencies. The West Coast Ship Pool is a prime example; it permitted DREP to carry out multi-ship operations, even after the DND contribution to the Pool had been reduced to one vessel. Another was the use of National Aeronautical Establishment (NAE), Maritime Proving and Evaluation Unit (MP&EU) and Canadian Forces (CF) operational aircraft in support of the Magnetic Anomaly Detection (MAD) program. More extensive was the support provided to operations in the Arctic in terms of fixed wing aircraft, helicopters, icebreakers, supply ships, submersibles, divers, hydrographic surveys, and base support. The SHIP REPAIR UNIT PACIFIC also increased the effective size and capability of the Laboratory by providing the personnel—on average, seven person-years per year—and specialized machinery required to construct equipment too large to be produced in-house.

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[1] One technique used extensively in the PNL years was to spot summer research assistants with exceptional promise and to offer them immediate employment, later upgrading their training with DRB supported graduate studies. This worked so well that it was also used in the early CRAD years, although later on, hiring was generally delayed until the completion of graduate studies.

The research program was further leveraged through international co-operation, frequently initiated and expedited through participation in The Technical Cooperation Program (TTCP), supported by the US, UK, Canadian, Australian and New Zealand defence departments. Through the resulting contacts, highly rewarding joint experimental programs developed, sometimes TTCP wide, at other times with the US and UK or bilaterally. Without such co-operation, it is highly unlikely that the towed array and mine countermeasures activities in DND would have reached anywhere near their current state of development. Although such co-operation can be initiated from the top, whether it flourishes or dies depends on the motivation and experience of the individual scientists directly involved and their need for expertise, facilities or other resources not available nationally. The Laboratory fared extremely well in such circumstances, being able to bring to the table well recognized expertise, capable research ships and access to the national resources mentioned above. Unsurprisingly, international co-operation and joint experimentation thrived and became an important feature of all the Laboratory's major research projects.

Historically, there was a high level of co-operation among Canadian West Coast research organizations in the operation of research ships. They were in fact treated as a pooled resource, informally at first, but by 1968, as the West Coast Ship Pool. Initially and for several years, the research ships were provided by DND. The first two, in operation at the time of the opening of the Laboratory, were HMCS CEDARWOOD and HMCS EHKOLI, both of whose operations eventually became confined to inshore waters. They were replaced in the mid-to-late 1950s when PNL's research program required more seaworthy ships, capable of extended operations in the open ocean. In 1956, HMCS CEDARWOOD was replaced with a minesweeper, HMCS OSHAWA. It became civilian manned in 1958, thus ending a decade of rewarding interaction between the Naval crews of the research ship and PNL scientists. In the same year, CNAV EHKOLI—an auxiliary vessel since 1950—was replaced by the minelayer, CNAV WHITETHROAT. Research ships were again replaced in the mid-1960s, by CNAV ENDEAVOUR—DRB's first purpose-built research ship—in 1965, and by the converted supply vessel, CNAV LAYMORE, in 1966. When LAYMORE was retired in 1976, it was not replaced, the Department of Fisheries and Oceans having by that time built up its fleet to the point where the Pool could operate satisfactorily with a reduced DND contribution.

The primary role of the Laboratory was to provide both the research and the technical expertise required by the maritime forces in underwater surveillance (acoustic, electromagnetic and fluid dynamic), mine countermeasures and materials technology. Although the latter activity was initially directed at ship-related problems, many of the results were also applicable to aircraft; over time, the materials program evolved to provide comparable levels of support to both the Navy and Air Force. Brief summaries of the principal research activities follow.

Ocean Acoustics

The Laboratory's first research project was an investigation of the acoustic factors that affect submarine detection by active sonar. This flowed naturally from the experiences in World War II where the primary underwater threat was the torpedo-carrying submarine attacking surface ships. Extensive large-scale modelling studies of sound propagation at the higher frequencies used in active sonar were conducted in the various channels abutting Vancouver Island. This led to an impressive demonstration of the impact on sound propagation, and hence on sonar performance, of the interfering rays of direct and surface reflected paths.

By the mid-1950's, the ballistic missile submarine became the target of principal concern, thereby causing the first of the major changes experienced over the years by the Laboratory's underwater acoustic program. As long-range detection in deep water now became essential, practicalities shifted the emphasis of the program to much lower frequencies and to passive sonar. Full-scale acoustic investigations in the deep waters of the North Pacific were required thus necessitating the acquisition of more-capable research ships and substantial co-operation with US scientists addressing the same problem. These deep-water investigations were supplemented by model studies in the Esquimalt Lagoon that achieved a number of telling insights on the effect of surface waves on the propagation of low-frequency sound.

In the late 1960s and early 1970s, there was a return to active sonar, motivated by the interest of the Air Force in localizing the targets detected by their sonobuoys. The effort focussed on studies of reverberation due to waves on the surface of the ocean and marine organisms in its volume. Extensive surveys were conducted of the volume reverberation in the Gulf of Alaska and as far south as Hawaii.

By the early-1970s the USN had shown that towed arrays were a promising way for surface ships to detect and maintain contact with submerged nuclear submarines. Thus the Laboratory began a program to examine the effectiveness of these arrays for underwater surveillance in the North Pacific. Investigations were conducted on: the flow noise of towed arrays and its dependence on tow-speed; the directionality of ambient noise in the ocean and its dependence on shipping patterns; sound propagation and its dependence on seamounts and the geophysical properties of the ocean bottom; and the development of a suite of passive ranging techniques based on angles-of-arrival and time-delays of multi-path propagation, and matched field and other sophisticated array processing techniques. As these techniques require realistic sound propagation models to be effective, a very considerable expertise and modelling capability was built up in this area. Particularly noteworthy were the contributions to the development of the parabolic equation propagation model, an accurate and high speed algorithm that made feasible real-time sonar performance predictions and the sophisticated array processing techniques.

As the development of techniques and equipment proceeded, they were tested and demonstrated in a series of military training exercises—approximately one per year—in which scientists and military personnel co-manned the towed array installation on CFAV ENDEAVOUR. This activity proved to be extremely useful in keeping the scientists and military closely attuned to the practical problems involved in towed array operations, and in indicating the most pressing areas for future research. The experience gained in these exercises and the expertise developed in the associated environmental acoustics program were employed in a series of system studies relating to the expected performance of towed arrays deployed from surface ships and submarines. These studies plus the demonstrated effectiveness of towed arrays for detecting and tracking submarines were influential in the decision of the CF to develop the CANTASS tactical towed array system for the patrol frigates.

In the 1990s, a research prototype, state-of-the-art towed array surveillance system was developed at DREP and trials conducted. However, the winding down of the Cold War and the resulting reduced threat from ballistic missile submarines precluded its further development.

Arctic Acoustics

Research in northern waters eventually was to become the Laboratory's single largest activity. The first experiments were conducted from CEDARWOOD in 1949, as part of a Can/US co-operative field trial to conduct oceanographic, acoustic and biological measurements in the North Pacific and the Bering and Chukchi Seas. It was followed in the summers of 1951 and 1952 by experiments carried out from CANCOLIM II in the Amundsen Gulf and southern Beaufort Sea, in co-operation with scientists from other government departments and UBC. The resulting oceanographic and hydrographic measurements later proved to be highly relevant to industry following the discovery of oil in Bering Strait.[2]

A hiatus in Arctic research then ensued until 1959 when ambient noise and sound propagation measurements were conducted in the ice-covered waters of Barrow Strait. This was the first in a series of measurements to determine the feasibility of underwater surveillance in the possible submarine transit routes through the Arctic. From this point on, at least one expedition per year took place either in the Arctic Channels or the approaches thereto. As a result of these activities, a commendable expertise was built up, not only in the acoustics of Arctic waters, but in the design and development of equipment that would operate dependably in the extreme cold, and the techniques required to conduct experiments and survive in this hostile environment.

By the early-1970s, the preliminary surveys—employing field parties on the ice, remote instrument packages placed on the sea floor, and telemetry buoys frozen into ice floes—were completed; noise levels and sound propagation were such that underwater surveillance in the transit routes appeared to be feasible. System studies, and additional experiments concentrating on more detailed investigations of the acoustics in selected areas of the channels were then conducted. The latter involved experimental bottom-mounted installations connected to shore, an arrangement lending itself to long-term measurement of background noise and for evaluating system performance on a year-round basis. Destruction of the cables at the shoreline by moving ice was initially almost an annual occurrence in some areas. This problem was ultimately addressed by bringing in oil-drilling crews to make conduits for taking cables from the beach to depths exceeding those expected for the deepest ice-keels.

By the 1980s, the experimental program began to focus on the waters of the Arctic Basin, primarily those north of Ellesmere Island. The program was expedited considerably by the presence of ice-shelves and ice-plugs at a number of locations on the north shore of the Island that served as stable platforms for making long-term acoustic measurements. In the mid-1990s, and in co-operation with several US laboratories, research arrays were placed on the bottom in deep water several tens of kilometers north of Ellesmere Island. This involved the development under contract of a state-of-the-art underwater cable-laying submersible, an achievement made possible through the expertise residing in the British Columbia underwater technology industry.

Over the years, a plenitude of equipment and facilities was designed or developed in-house to support the Arctic research program, including: clothing; shelters; hot-water ice drills capable of penetrating the thickest ice; hot-water 'cookie cutters' that permitted the removal of the large blocks of ice from ice-floes required for the immersion and recovery of large equipment such as the cable-laying vehicle *Theseus*; ice groomers to smooth the surface of ice-floes to permit the landing of fixed-wing aircraft; flow shields to permit hydrophones to monitor the very quiet noise levels frequently encountered in ice-covered waters; and remote instrument packages for making year-long autonomous measurements of ambient noise under ice. Scientists and engineers from the Laboratory became well recognized for their expertise in installing underwater equipment, including wide-aperture arrays, and in the development of the matched field processing techniques required to optimize their performance.

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[2] Following which, a combined government, industry program was initiated in 1973 to conduct a geophysical survey of the Beaufort Sea. Al Milne, the leader of the Arctic Acoustics Group, transferred to IOS to become the manager of this project.

Fluid Dynamics

In 1951, an investigation was initiated to see if the turbulent wakes generated by submarines in the open ocean could be detected. As this was an untilled field, it was first necessary to develop the appropriate measurement sensors and their associated calibration and test facilities. A large low-turbulence water tunnel—built in Germany to PNL specifications—arrived in Victoria in late-1955 and was installed in the basement of the recently completed main laboratory building. By 1959, sensors suitable for measuring the small scale temperature and sound velocity fluctuations expected in ocean turbulence were developed. Experiments were then conducted on the natural background in the highly turbulent Discovery Passage. The results attracted wide interest internationally, as they verified the theoretical form of the turbulence spectrum deduced twenty years earlier.

In 1960, the state of the instrumentation was such that it became feasible to address the problem of ship generated wakes; the turbulent wakes from two surface ships operating in calm seas were detected using hot-film probes deployed from a surface ship. Encouraged by this demonstration, equipment was installed—in 1961 and 1962—on the submarine HMCS GRILSE, both to extend the studies to the natural turbulence in the open ocean and to permit the measurement of submarine generated wakes. The operations were successful in that it was found that submarine wakes were persistent and observable. Unfortunately, these same observations revealed unexpected patches of natural turbulence in the thermocline that could not be distinguished from wake turbulence. Because of depth limitations on the submarine, it was not possible to conduct measurements of the natural turbulence at depths below 300 feet. Accordingly—in 1965—sensors were fitted to a streamlined instrument platform towed from CNAV ENDEAVOUR to investigate this background temperature and velocity microstructure down to 1,200 feet. Patches of natural turbulence were found even at this depth.

At this time, theoretical and experimental investigations were commenced on the visible surface effects arising from the interaction between surface waves and internal waves produced naturally or by various dynamic interactions between hulls or ship wakes and the density layering usually found in ocean water. By 1970, a decision was made to focus the fluid dynamics effort on this phenomenon and the work on ocean microstructure was handed over to the Institute of Ocean Science (IOS) who subsequently launched a substantial program in this area.

In 1971 and 1972, research concentrated on an investigation of those factors that affect the visibility from the air of internal waves. Photographs were taken from a helicopter of internal waves generated by ENDEAVOUR in Georgia Strait and Bute Inlet. The ship having generated the internal waves, then returned through the wave field to measure directly the perturbations of the sea surface. The results were later compared with those of the aerial photographs to determine the relationship between visibility, wave slope, surface current and wind speed. Contracts were subsequently let for laser scatterometers suitable for conducting measurements from fixed-wing aircraft of patterns on the sea surface due to internal waves. The initial measurements were conducted in 1981 and 1982.

As a result of its acknowledged expertise in surface manifestations of internal waves—and being the possessor of a unique scanning laser scatterometer—DREP became a participant, with a number of US laboratories, in two major investigations using synthetic aperture radar and near-IR scatterometry to study ship wakes, surface ship produced internal waves and naturally occurring internal waves. The first, the Joint CAN/US Ocean Wave Investigation Project (JOWIP), took place in Georgia Strait in 1983, and the second, the Synthetic Aperture Radar Signature Experiment (SARSEX), in Long Island Sound in 1984.

The experiments were successful, with simultaneous and coincident images being obtained on a number of occasions by the scatterometer and the radar. As the next logical step in the study of internal waves required an as yet unbuilt state-of-the-art radar, whose costs well exceeded DREP's ability to finance, a decision was made to terminate the Fluid Dynamics program in 1987 and to re-deploy the staff to Arctic Acoustics.

Electromagnetics (surveillance)

In 1953 a request was received from the Navy for assistance with the harbour defence loops situated near Albert Head. A preliminary investigation indicated that the loops were working well and that significant gains in performance could be achieved with only a modest increase in cost and complexity. It was observed that the loops were responding—for the most part—to the natural geomagnetic background, thus sparking the Laboratory's interest in the characteristics of the responsible mechanisms.

An extensive investigation of the natural electromagnetic disturbances began in 1955 with the hiring under contract of Sir Charles Wright, a distinguished scientist and administrator—and participant in the ill-fated Scott Polar Expedition of 1911-1913—who throughout his life was intensely interested in the geophysics of the upper atmosphere and associated electromagnetic phenomena. Initially, in 1957, large electromagnetic arrays were installed onshore at Albert Head to examine in detail the fundamental electromagnetic factors that controlled the performance of the Navy's harbour defence loops. The following year began an extension of the program to observe the characteristics of magnetic fields at widely separated locations. Measurements were made at other locations in British Columbia, at Suffield and in the California desert. An investigation then began of the effect of the shoreline on the electromagnetic background, a problem of considerable defence interest, and one which attracted the attention of scientists at the Laboratory and local universities over many years. Next followed the *conjugate point experiment* in which the electromagnetic background at Great Whale River in northern Quebec was compared with that at the other end of the same magnetic flux line at Byrd Station in Antarctica. Measurements made in 1961 by PNL staff showed that large impulsive events, associated with intense auroral displays, occurred simultaneously at both locations. In addition, continuous signals lasting for several hours, and attributed to world-wide lightning, were observed simultaneously at Byrd Station, Great Whale River and Albert Head. A happy byproduct of the experiment was that it provided Sir Charles with the opportunity to visit the South Pole and to revisit the still-standing buildings and facilities in which he had worked and lived a half century earlier.

Based on the results of the various experiments conducted up to the mid-1960s, it seemed that it might be possible to cancel out the common portions of the background noise received from nearby fixed sensors, thus significantly improving system performance. By the early 1970s, suitable cancellation techniques had been developed and tested on the earlier data. The resulting improved performance made feasible the detailed examination of ship radiated electromagnetic signals, a capability that began to be exploited at that time. The program next focussed on measuring ship radiated signals at the Nanoose Tracking Range and in conducting environmental and system performance studies at a number of Arctic locations—Assistance Bay in Barrow Strait (1974-1980), the western end of Jones Sound (1981), and north of Alaska (1982-1989). In the 1990s the program again moved south, with co-operative trials being conducted with the US at Neah Bay, Washington, from 1992 to 1995.

Electromagnetics (MAD)

In 1961, a project was initiated, in co-operation with the National Aeronautical Establishment, to study the limitations on airborne magnetometry imposed by geomagnetic and geological noise. During the early 1960s, aeromagnetic surveys were conducted off Sable Island, California and the Bahamas. They were supplemented in 1966 by experiments using lines of magnetometer buoys off the east and west coasts of Vancouver Island. As a result of these experiments it was determined that magnetic signals generated by long-period ocean swell place an important limitation on the performance of MAD systems operating from low-flying aircraft. The investigation of this phenomenon continued over the next three years with airborne and ocean wave measurements being made simultaneously from the NAE North Star aircraft and an off-shore oil-drilling platform respectively.

In 1968, a DRB Advisory Committee on MAD Research and Development was formed to ensure that the needs of the CF were properly addressed by the R&D being conducted by the CF, DRB, other government departments and industry. An early action of the Committee was to task DREP and NAE to carry out a quantitative analysis of the various noise factors affecting current and future operational MAD. The results of this study had a considerable impact on later R&D in both the government and industry. Over the next several years the DREP program focussed on the identification of noise sources and their characteristics, the development of automatic detection algorithms and the advantages of including gradient information in MAD systems.

The development of computer-aided detection for MAD began in 1973. By 1979, a system based on a commercial mini-computer was flown and tested on a CF Argus. Two years later a micro-processor based version was evaluated on the recently purchased CF Aurora aircraft, very successfully as its performance not only equalled that of a human operator but it made faster decisions. The effectiveness of the combination of the DREP detection algorithm and a CAE MAD system was then demonstrated on a US Navy helicopter. This stimulated the CF to order a prototype inboard MAD system and CAE to develop the AIMS system—combining their optically-pumped magnetometer and aircraft compensation system with the DREP detection algorithm—for fixed-wing aircraft and helicopter use. This turned out to be a highly successful example of co-operation between government and industry, resulting in substantial foreign sales and significant royalties paid to the government.

For a MAD system to operate satisfactorily, it must be compensated for signals induced by the movement of the aircraft through the earth's magnetic field. Compensation algorithms—including some developed co-operatively by DREP and NAE—are available to accomplish this. Historically, aircraft compensation involved aircraft manoeuvres of such violence that aircrews tended to avoid them to the detriment of system performance. Investigations at DREP, beginning in the early 1980s, showed that in fact less violent manoeuvres involving little aircrew discomfort provided superior compensation. This went a long way towards ensuring that the aircrews would update the compensation at frequent intervals, thus optimizing MAD system performance. In the 1990s, a further development, conducted in co-operation with industry, made it possible to do away with the manoeuvres entirely and compensate automatically using the normal motions of the aircraft.

The magnetic state of an aircraft, particularly of helicopters, with their flexible airframes, rotating blades, and machinery in close proximity to the magnetometer, is critical to the successful operation of MAD. DREP scientists became very proficient in identifying electromagnetic problems in helicopters and devising cures. This capability, developed to improve the performance of MAD, was later put to good use in another context, diagnosing and eliminating a serious problem with the navigation systems of CF helicopters bound for the Gulf War.

Thanks to these various activities, DREP played a prominent part in demonstrating the feasibility of helicopter inboard MAD and bringing its performance close to that for a fixed-wing aircraft. This was a remarkable achievement that placed Canadian industry in an enviable position worldwide.

Beginning in the early 1970s, DREP scientists also took a leading role in investigating the feasibility of building more effective MAD systems by using gradiometers. The potential usefulness of this approach was demonstrated in 1981, when a multi-component superconducting gradiometer was towed on a catamaran along the Pitt River to obtain geological and target data. Although subsequent research indicated that there was no fundamental reason why the technology could not be applied to airborne platforms, tests to date indicate that successful implementation may still be some years off. The main positive outcome to date is the fact that Canadian Thin Films (CTF), introduced to this area by DREP who then supported it with substantial research contracts, has developed a multi-million dollar per year export business—probably the world's largest—in biomagnetic magnetometers.

Mine Countermeasures

Throughout the first half of the 1950s, a small effort in the form of system studies was devoted to mine countermeasures (MCM). The expectation was that either UK or US minehunting equipment would become available whose performance could be evaluated under local conditions. When this did not occur and as there was at the time very little interest in the subject by the Canadian military, the project was terminated. There was, however, an awakening of interest in the mid-1970s which led to the Washington Liaison Office assuming observer status in GTP-13, the TTCP Mine Countermeasures Panel. Although this sufficed to bring DND up to date on developments in allied countries, a much more active role was called for so, in 1979, DREP became a full member and enthusiastic participant in the Panel. Shortly thereafter, it was decided that the most effective contributions that the Laboratory could make to MCM were in route surveying and ship quietening.

The approach adopted for route surveying was to survey the ocean bottom using side-scan sonar. Through precise navigation, the position of all minelike objects would be mapped and then updated by later surveys. Thus if a new object with mine-like characteristics appeared in the survey area it could be treated as a possible mine and the appropriate action taken. Routine surveys to define the background conditions could be accomplished most efficiently by towing the sonars from surface ships. In the absence of expensive, purpose-built minehunting vessels—a situation applying to most countries, including Canada—this would not be a valid strategy in the final minehunting phase where live mines might be encountered; the sonar would have to be towed from a small remotely operated or autonomous vehicle, with the mother ship stationed outside the danger area.

The local underwater technology industry possessed considerable expertise in side-scan sonar, navigation, underwater vehicles and signal processing, all of which are required to make a success of the selected approach. As far as possible, commercial equipment would be used with any modifications required to adapt it to route surveying or minehunting being carried out under contract. With this approach, it was possible, by the fall of 1984, to provide the Fleet Diving Unit (Pacific) with the advice, assistance and equipment—sidescan sonar, precision navigation system, and a Remotely Operated Vehicle (ROV) for examining mine-like targets—for a very successful minehunting exercise in Esquimalt Harbour. Later, in 1987, the Laboratory participated in a similar exercise carried out in the highly cluttered and hence technically difficult approaches to Halifax Harbour. It was quite successful in that it demonstrated to the CF the validity of the DREP's unique approach to minehunting, and to defining those areas where additional refinements were most in need. The various capabilities required for an operational system were developed in co-operation with industry and tested in numerous field trials on both the East and West Coasts: commercial side-scan sonars were evaluated; towed body dynamics were simulated; a servo-controlled bottom-following winch was developed; techniques for mapping or geocoding sonar images were developed; tests were conducted of the relative stability of sonars towed by surface ships and the ISE semi-submersible, *Dolphin*; the towed underwater vehicle *Manta* was successfully fitted with a swim-ahead capability; and a state-of-the-art precision navigation system and high speed warping techniques to facilitate the interleafing of target data from different surveys were developed. Progress was such that, in 1993, the CF decided to incorporate route surveying based on the DREP approach in their Maritime Coastal Defence Vessels (MCDVs).

Electromagnetic currents flowing in a ship's hull radiate signals that can be used to detect the presence of the vessel or to trigger a mine bent on its destruction. Of particular concern are the currents that flow between the hull and propellers. The same currents can also cause extensive corrosion to the ship's hull and fittings. Thus, even several years prior to the initiation of the MCM program, this problem was being addressed by the Laboratory's corrosion scientists. By the 1970s, DREP had produced an active shaft-grounding system, installed it on CNAV ENDEAVOUR and tested it for its ability to reduced radiated electromagnetic signals. As the device appeared to be very significant not only for the ships of the CF but as a potential source of sales to allied navies, a decision was made in the early 1980s to encourage Canadian industry to exploit this opportunity. Units produced by Davis Engineering excelled in a CAN/US/UK test of competing technologies conducted in 1985 off Fort Lauderdale. Due in large part to the foresight in establishing a production facility in industry, sufficient units were available when the Gulf War came along to equip all the Canadian ships sent to the Gulf. The shaft-grounding units also became a commercial success with—by mid-1997—eighty units having been sold to Canada, the US, the UK and France, and with orders pending from several other nations. A similar approach had been adopted for a second countermeasure to eliminate the signals radiated by ships' cathodic protection systems. Again, through industrial involvement, sufficient units were available to fit the Gulf-bound ships. Fortunately DREP had earlier installed electromagnetic sensors in both Halifax and Esquimalt Harbours which were available to check out the effectiveness of the installed countermeasures.

These were not the only contributions of the MCM Group to the Canadian naval effort in the Gulf. Shortly after the invasion, the Group Leader proceeded to Halifax, where for several weeks he led a DREA/DREP study team investigating the feasibility of using commercial fish finding sonars in mine avoidance. Following system studies and trials in Bedford Basin, sonars were fitted to three ships proceeding to the Gulf and on one serving as a test vehicle in Halifax. Through the efforts of the study team, the task force was provided with a sonar prediction capability and an MCM oceanographic atlas of the threat zone. How much the various activities of the MCM Group contributed to the safety of the ships is uncertain, but anecdotal evidence indicates that they were significant. Certainly this is a splendid example of how a well worked-up research team can respond to an emergency situation.

Materials Technology

Materials research at PNL began in 1950 with a search for the most effective means of employing cathodic protection and improved paint systems to prevent the corrosion of ships' hulls. The payoff from this work was substantial; by the 1960s the time between drydocking of the Navy's ships increased from six months to four to five years. In 1952, a metals-chemistry group was added to provide scientific facilities and technical assistance to the Dockyard. By the mid-1950s, the effort in materials had grown to include five technical areas: analytical chemistry, physical metallurgy, nondestructive testing, anti-corrosion and paint. An important activity at this time was the radiographic analysis of the welds in the hulls of RCN ships, either under construction or operational. Increasingly, the ability of the Section to respond rapidly and efficiently to requests for assistance from the Dockyard and operational forces became recognized; by 1955 these requests rose to approximately 800 per year.

In the early 1960s, research began in a number of areas which—like cathodic protection and paints—over the years, provided substantial opportunities for innovation and discovery. The *in-situ* determination of wall thickness of boiler and superheater tubes of RCN ships replaced the destructive 'wear and waste' method that had been in vogue in the world's navies for the preceding century. Initially, Thulium 170 nuclear gauges were employed, but they were later replaced with ultrasonic transducers. In the 1990s, a commercial automated unit based on DREP technology won an international competition—sponsored by a consortium of pulp companies—for boiler inspection systems.

Research in chemistry focussed on methods of extending the capabilities of the Laboratory's spectrographic facilities. Flame spectrometry proved to be particularly useful in detecting metallic contamination in lubricating oils, a method which became standard for testing the lubricants on Navy ships. In the late 1960s, the program was extended to include the aircraft at CFB COMOX. Research was also conducted on a complementary technique, ferrography—where metallic particles in the lubricant are sorted according to size—resulting in the development of an on-line analyser, Ferroscan, for use on ships and aircraft. As filtering had reached the point in the 1980s that there was little debris left to analyse in engine lubrication oils—the CF-18 being a prime example—research then concentrated on techniques for analysing the debris in the filters.

In 1970, the grounding of the oil tanker ARROW in Chedabucto Bay presented DREP scientists with another opportunity to demonstrate responsiveness to a high-profile emergency. Of the hundred plus inventions considered for cleaning up the oil in the water and on the beaches the Slick-Licker invented by a DREP scientist was easily the most effective. Knockoffs of this device are now commonplace in the harbours of the world.

The 1970s also saw the materials program expand to provide appreciable additional support to the Air Force. Radiographic studies were conducted of the structural members of aircraft, and research was initiated on the use of ice particles as an abrasive for stripping paint from aircraft fuselages, where competing processes cause unacceptable damage. Units have been sold by a DREP contractor to both the aircraft and automobile industry.

A Composites Group was formed at this time, motivated by the anticipated arrival of the CF-18 fighter aircraft, which included extensive use of carbon fibre composites in its construction. Emphasis was given to the identification, damage tolerance analysis and repair of defects in these composites, including those related to battle damage. Techniques were developed to permit such damage to be repaired in the field. This involved the development in-house of a special adhesive, commercial products being found inadequate. A robotic system using ultrasonic sensors was developed for the nondestructive detection and evaluation of flaws in the aircraft's wings. Signal processing techniques developed under contract were used in conjunction with the ultrasonic scanner to provide more accurate assessments of the defects than had previously been possible. Copies of the software were later sold to commercial airlines in the US and UK. DREP studies of the size, distribution and growth of defects related to the delamination of composites indicated that the criteria adopted by aircraft manufacturers for repair and maintenance could well be relaxed, with considerable saving in aircraft downtime and costs.

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Although the emphasis varied from program to program, all had substantial and rewarding interactions with the military customer: in assisting with major development projects (mine countermeasures and arctic acoustics); in providing day-to-day technical services (materials technology); in participating in military training exercises (ocean acoustics and mine countermeasures); and in direct support to the ships and helicopters assigned to the Gulf War (mine countermeasures and magnetic anomaly detection). Most projects included joint experiments with our allies, effectively expediting the transfer of technology into the Department. DND also benefitted handsomely from the impressive savings due to reduced maintenance and increased operability arising from the materials research effort in corrosion, engine-health monitoring, nondestructive evaluation and coatings. Canadian industry also benefitted through the technological and financial support provided by the Laboratory, which in a number of instances culminated in substantial developments and sales; the assistance provided by the scientists from the Electromagnetics Section proved to be particularly rewarding in this regard with major exports arising in MAD systems, electromagnetic ship-quieting devices and biomagnetic magnetometers.

Many of the scientists became world recognized experts in their fields. Oft-quoted, sometimes definitive papers were published on turbulent microstructure, interactions between surface and internal waves, Arctic ambient noise and reverberation, sound propagation, advanced array processing, corrosion, metal fatigue, and electromagnetic phenomena related to ocean swell, the shoreline and conjugate points of magnetic flux.

Prior to the closure, there was some speculation that the Laboratory's future was in doubt. Those in the CF whose programs were most dependent on DREP made their concerns known, with support being particularly strong for the work being carried out in maritime materials and mine countermeasures—the latter in direct support of the ongoing MCDV acquisition program. There was also general agreement that the research in Arctic acoustics should be supported, at least until it reached a logical stopping point. In response, CRAD initiated a study of how best to retain core expertise in the most critical components of the research program in the event that the status quo could no longer be maintained. In due course, DREP did close, but its most strongly supported programs survived.[3] The closure, though regrettable, was not an isolated event but part of a world-wide downsizing in defence initiated by the collapse of the USSR in 1989. Although it is the end of an era, the staff can, in looking back over the Laboratory's forty-seven years of existence, well be proud of their accomplishments and the culture which evolved to make them possible. It was both a pleasure and a privilege to work in this environment.

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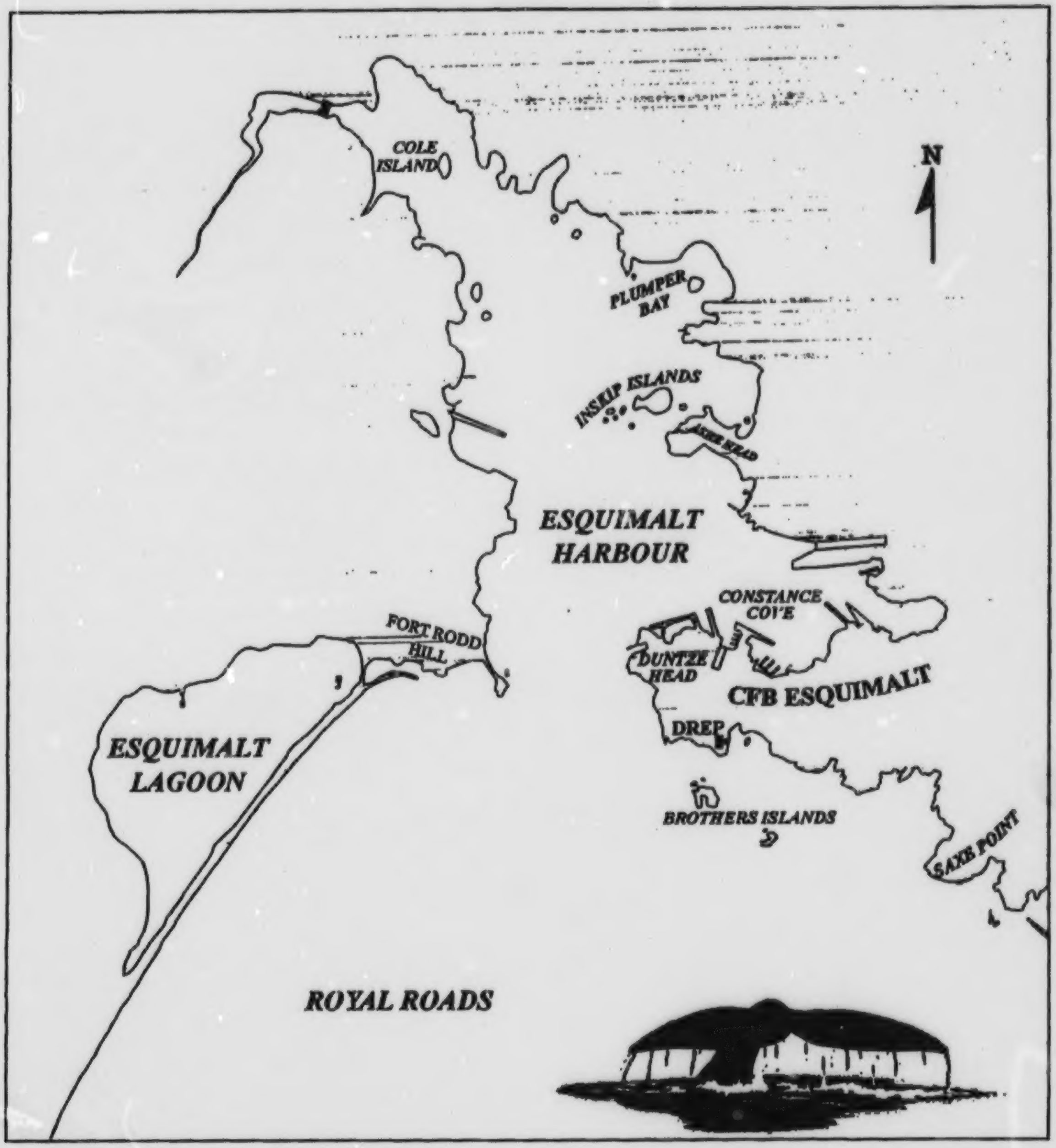
[3] From the closure in April 1995 until April 1998, these programs were continued at the Esquimalt Defence Research Detachment in Victoria BC, a research division of the Defence Research Establishment Atlantic in Dartmouth NS.



CFB ESQUIMALT and DREP

1. DEFENCE RESEARCH ON THE WEST COAST

R. P. Chapman

Budget '94

It was announced in the February 22, 1994 Federal Budget that due to the winding down of the Cold War and the state of the country's finances, it had become both possible and essential to carry out a very substantial downsizing of the Department of National Defence. An early casualty was the Defence Research Establishment Pacific (DREP) which was closed on 31 March 1995. This informal history recounts its achievements and the principal events and personalities which shaped its destiny. The first chapter is an account of the Laboratory's principal research activities, divided chronologically into sections corresponding—approximately—to the tenures of its succession of senior managers. Later chapters feature more anecdotal accounts of specific areas of the research program.

1936 to 1945 - pre-war and wartime[1]

Co-operation between marine scientists and the Navy on the West Coast has a long and distinguished history, beginning as early as the mid-1930s. In both 1936 and 1937, Dr John P. Tully of the Pacific Oceanographic Group (POG) of the Department of Fisheries in Nanaimo, working from the minesweeper HMCS ARMENTIERES, carried out four oceanographic cruises in the Northeast Pacific. They provided the first synoptic information on oceanographic conditions off Canada's west coast. The data collected on these cruises, and on later surveys concentrating on the entrance to Juan de Fuca Strait, were used in World War II in the analysis of sound ranging conditions in Pacific waters. Dr Tully continued his oceanographic studies during the war, and in 1943 began to use the 85-ft motor vessel HMCS EHKOLI as his principal research platform.

Dr Tully was largely responsible for alerting the navy to the relevance of oceanography to its operations, and to its practical implementation, an activity which he continued to pursue with characteristic vigour and enthusiasm into the 1960s. He also had considerable success in organizing co-operation between the various West Coast organizations conducting marine research, particularly in the area of research ship utilization. His efforts eventually led to the creation of the West Coast Ship Pool, a model of co-operation between federal and provincial government departments, and universities. It is therefore fitting that the most modern and capable research ship on the West Coast, the JOHN P TULLY, was named in his honour.

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[1] Information on pre-war and wartime activities and much of the information on research ships is taken from a memorandum on "Canadian Naval Oceanographic Research Vessels," Capt R.G. MacDonald (Master CNAV LAYMORE) and F.D.H. Nelson (Base Historian, CFB ESQUIMALT), 16 pp, 20-2-1992.

1946 to 1948 - early post-war - the beginnings of DRB and PNL

Following World War II it was decided that the needs of the Department of National Defence (DND), and the Canadian Forces (CF) in particular, for scientific advice and assistance could best be met by combining the various research and development centres set up during war-time into a centralized organization. This was achieved on 1 April 1947 with the formation of the Defence Research Board (DRB). Due to a number of factors, including the inadequacy of the temporary wartime accommodations and the desire of the National Research Council (NRC) to withdraw from classified R&D in peacetime, the facilities available were insufficient for the prosecution of DRB's mandate. Accordingly, a number of new facilities were opened, one of which was the Pacific Naval Laboratory (PNL) in Esquimalt—some years later renamed the Defence Research Establishment Pacific (DREP).

EHKOLI

1948 to 1953 - the formative years[2]

Organization, facilities and trends

On 16 August 1948 Dr F.H. (Fred) Sanders, a former NRC scientist with a background in electromagnetics and acoustics, was appointed Superintendent and immediately proceeded to open the Laboratory with a staff of two scientists—Messrs P.W. (Pat) Nasmyth and H.H.A. (Harry) Davidson—both electrical engineers and also former employees of NRC, and an Administrative Officer, Mr H.E. (Harry) Bell.[3] Space for PNL was provided within the Esquimalt Dockyard in a group of four wartime huts which had housed the crew of a gun emplacement on Black Rock. The building which had been used as a canteen was

PNL buildings at Black Rock

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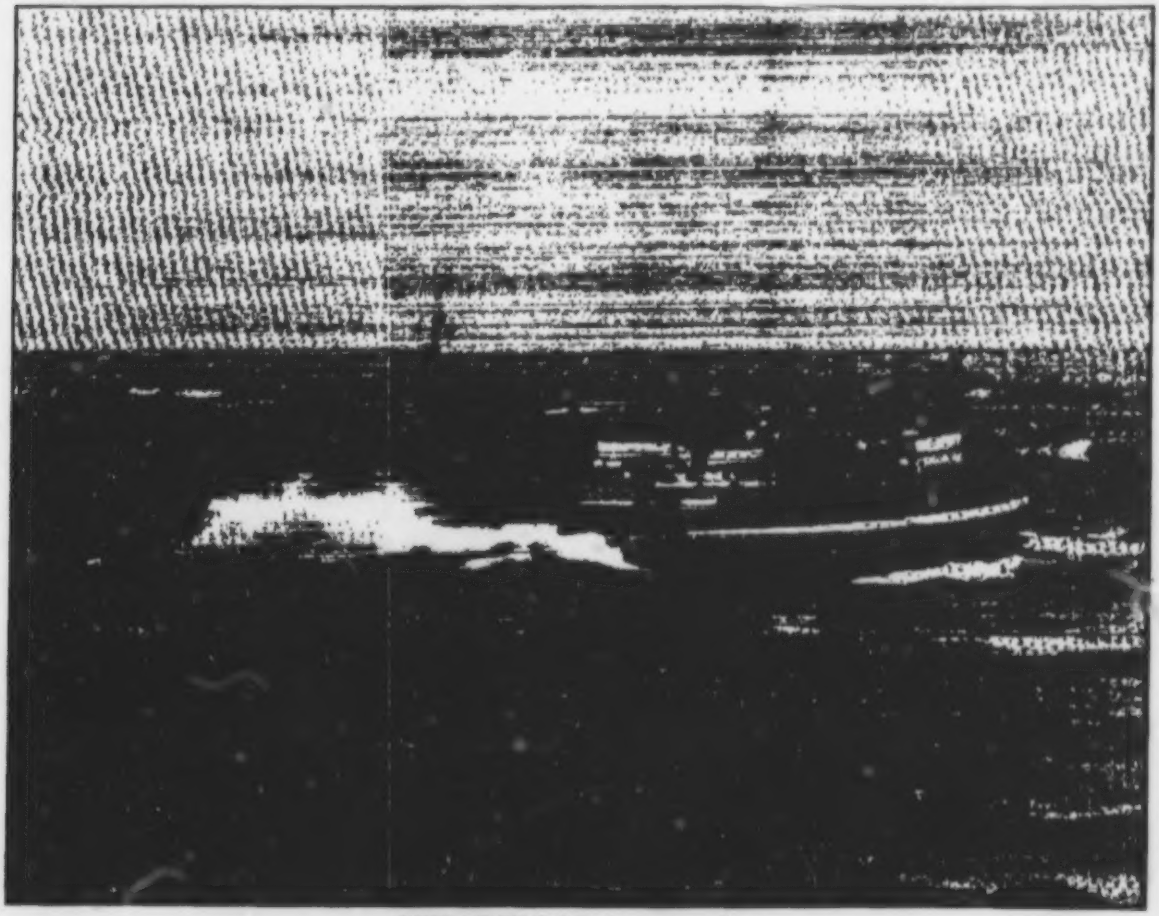
[2] Much of the information on the beginning and early life of PNL is taken from a memorandum on "The Pacific Naval Laboratory—its origin and history," F.H. Sanders, 5 pp, 1967.

[3] They were later joined by a secretary, Miss Adelaide Simpson, who is given considerable credit for the efficient running of the Laboratory in its early years.

chosen for the first laboratory work space, while the Superintendent and his administrative staff were installed in an adjacent building.[4]

The first objective of PNL was to undertake research on the underwater acoustic characteristics of West Coast waters and their effect on sonar performance. This was expedited thanks to the previous efforts of Dr Tully who had persuaded the RCN to acquire the MV GENERAL SCHMIDLIN—a 155-foot, Nova Scotian-built wooden vessel constructed as a supply ship for army outposts—to support marine research on the West Coast. After being transferred to her new tasks in Esquimalt she was re-named and commissioned HMCS CEDARWOOD. She became PNL's first major research asset, and for the next eight years, she, along with the EHKOLI, satisified the research requirements of PNL and POG, and earned the loyalty of successions of sea-going scientists, in spite of an alarming tendency to roll her rail under in a blow. However, by 1951, the ship's condition had deteriorated to the point where it could no longer be operated off-shore. Although confining its activities to coastal waters was not then a serious impediment, it placed an unacceptable constraint on future planning and operations. Thus serious consideration began to be given to obtaining her replacement.



CEDARWOOD bows under

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[4] Conditions were fairly basic; heat was supplied at first from individual coal-burning stoves for which fuel had to be 'scrounged' from adjacent Dockyard coal piles.

By the beginning of the 1950s the Laboratory had begun to expand its program into a number of additional areas of technology, a process soon to be dramatically accelerated by the increased emphasis on defence resulting from the 25 June 1950 invasion of South Korea by the North, which launched the Cold War in earnest. Dr O.M. Solandt, the Chairman of DRB, in his annual address on 30 March 1951, outlined the situation at DRB at that time with the resulting opportunities and challenges.[5]

> Throughout its brief history all the Board's work has been marked by an excellent unity of purpose and team spirit. When the organization was small it was quite easy to maintain this atmosphere, since every member of the staff was able to know what was going on and to see how his particular job was contributing towards the realization of the major tasks that the Board undertook. Now that the staff is getting larger, the organisation inevitably gets broken up into sections dealing with relatively narrow fields. This compartmentalization in turn means that many members of the staff know only about the accomplishments or difficulties and frustrations in their own particular spheres. They often do not see how the jobs they are doing are related to the larger purpose of the Board. When this happens, initiative declines and team spirit weakens. As an organization, we must strive to retain unity of purpose and enthusiasm for our work.

The loss of unity and team spirit due to growth never really became a problem at PNL. Although the staff had increased from the original four in 1948 to thirty-six by the end of 1952, the laboratory was still relatively small, and remained so throughout its working life. At the time of Dr Solandt's address, and for at least another decade, the size of the staff and the demands placed upon it precluded compartmentalization; most members of the staff worked on a number of problems, often in different technical areas. This meant that most everyone knew what the others were doing and had a vested interest in their success. In addition, much of the work involved fairly extensive field trials requiring for their success essentially the full range of talents and capabilities available in the laboratory. The field parties soon developed an enviable expertise in the design and conduct of experiments, often carried out in uncomfortable, even primitive conditions; an excellent team spirit was perhaps inevitable.

> The occasion of this gathering is the fourth anniversary of the founding of the Defence Research Board. Coincidentally it occurs at a time of far greater importance in the history of the Board than any mere anniversary. It marks the first real challenge to our growing organisation. When the board was first set up we had hoped that we would have more than four years in which to build up the organisation that would meet Canada's peacetime needs and also serve as a basis for mobilization in time of war. Now with our basic organisation well developed but still far from complete, we are called upon to join with the armed forces and all other elements of the nation in a partial moblization.... The first job the Board had to tackle was to build up a staff. This has proven to be a continuing project requiring a great deal of time and energy. The gains which have been made in the face of the general shortage of scientific personnel prove that the scientific reputation of the organisation is high....Making due allowance for the Board's youth and for the difficulties introduced by the necessity for security clearances, there is every reason for satisfaction in the rate of growth and in the high quality of the staff which is recruited.

As indicated by Dr Solandt, recruiting had been going extremely well, both in terms of quantity and quality. By late 1951, the number, quality and versatility of the staff had reached the point where it was possible to launch a significantly expanded research program. Recruited at the time were three scientists who were later to play distinguished leadership roles in the scientific community either within or outside the Department. Dr H.L. (Harold) Grant, recruited in July 1950, later became Chief of DREP. Dr R.W. (Bob)

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[5] "The Defence Research Board—The First Four Years," O.M. Solandt, an address to the staff of DRB in Ottawa marking the occasion of the Board's fourth birthday, Report NO. DR 34, 30 March 1951.

Stewart, who joined PNL a month later, was to become, in succession, a Professor at the Institute of Oceanography at UBC (IOUBC), the Director General of the Institute of Ocean Sciences (IOS), Pat Bay, the Deputy Minister of the Department of Science and Technology of British Columbia, the Director of the Alberta Research Council, and the Director of the Centre of Earth and Ocean Research (CEOR) at the University of Victoria (UVic). Dr W.N. (Bill) English, who was recruited a year later, became, after leaving PNL, the Director of the Bedford Institute of Oceanography (BIO), the Director of the BC Research Council, the Deputy Chief and Acting Chief at the Defence Research Establishment Valcartier (DREV), and the Deputy Director General of IOS.

> A continuing problem, almost equal in importance to that of personnel, has been that of accommodation. Most of the wartime research establishments which the Board took over were housed in temporary structures which were unsuitable for permanent use. Some new construction was started at once, and in 1949 a full-scale building programme, planned to extend over a five-year period, was launched.

PNL was a welcome beneficiary, having by then well outgrown its original accommodation. Construction started in January 1953 on a new laboratory building to replace the five temporary units then in use.

PNL building lot behind the church and near the main gate of CFB ESQUIMALT. The church was later moved to the east along Esquimalt Road. Photo circa 1900.

Mim Edmonds awaits, while Dr Sanders explains the ping reader to the Minister of National Defence, Brooke Claxton

Within its first five years, PNL had taken initiatives in all those areas which were later to dominate its program. Initially, ocean acoustics, concentrating on model studies in the waters between Vancouver Island and the mainland, was predominant. Then, in 1950, Mr J.A.H. (Jack) Carson joined PNL to work on problems relating to ship corrosion. In time, this effort was expanded to provide a much more extensive service in materials engineering support to the local maritime forces. In 1952, Mr R.D. Barer, who possessed an extensive industrial background in metallurgy, corrosion, paints and nondestructive evaluation (NDE), was hired to develop and manage this program, a task which he carried out until his retirement in 1987. From ocean acoustics there quickly developed a requirement for advanced oceanographic sensors, thereby spawning a well respected program in fluid dynamics. A request in 1953 from the Navy for assistance with their harbour defence loops, led, in a relatively short time, to a substantial program in electromagnetics. This program, involving extensive co-operation with many other research organizations, both nationally and internationally, later led to the Laboratory's heavy involvement with airborne magnetic anomaly detection (MAD) and was instrumental in its development of a major program in mine countermeasures (MCM). Throughout the early 1950s there was an MCM project on the books. Effort was, however, confined to paper studies and the maintenance of a watching brief on developments in the US and UK. It was intended that if minehunting equipment from either country became available for testing, PNL would respond with an enhanced program. This did not happen; at the time, western navies were reducing their interest in MCM, and this, combined with manpower constraints at PNL, caused the project to be suspended in 1956. The subject was not revisited until the mid-1970s, after which it gradually developed into the Laboratory's highest priority research project.

From very early on, the staff had taken an interest in the North. They recognized that the Beaufort Sea and Amundsen Gulf constituted a considerable portion of Canada's northern boundary, and that an understanding of their characteristics and behavior would be important both from a military and civilian point of view. Hence, they took every opportunity to encourage, contribute to, and within available resources, participate in projects to obtain oceanographic, hydrographic and underwater acoustic information in these areas.

As the technical programs expanded and became more diversified, a self-contained engineering support section was set up to be responsible for the design and construction of equipment which could not be obtained commercially. Electronic and mechanical engineering groups were initiated in 1951 and 1953 respectively. The Section head, until his retirement in 1973, was Harry Davidson. From the beginning, the practice was to have the engineering staff go on field trials to test, evaluate and operate the equipment which they had developed, a practice which contributed very substantially to the success of the major field trials which constituted the core of the Laboratory's research program.

Ocean Acoustics

Within weeks of the opening of the Laboratory, the small staff, with the very able assistance of Dr Tully, began its experimental sea trials program by participating in a major international research operation involving PNL, POG, the RCN, USNEL[6] and the USN. An impressive array of ships gathered in Nodales Channel, between Thurlow and Sonora Islands. Led by the large fleet class submarine USS BAYA, the fleet also included the American escort craft EPCE(R)857, HMCS CEDARWOOD, the Canadian ALGERINE minesweeper HMCS ROCKCLIFFE, HMCS EHKOLI, and an assortment of smaller craft. For the next six weeks, the local residents were entertained by the mysterious manoeuvres carried on by this small fleet, and a steady stream of fish boats found it necessary to pass through the normally unfrequented Nodales Channel. Following the operation, US and Canadian scientists combined their efforts to produce a substantial report placing sonar performance prediction on a strong scientific footing. Overall, this exercise provided a splendid beginning to the international co-operation which was to became a hallmark of the PNL/DREP research program.

For several years following this operation, PNL staff carried out operations in the same Nodales Channel, which provides unique features suitable for sound transmission measurements. The emphasis was on the investigation of the characteristics of underwater sound fields, particularly their variations with time and space. One of their more interesting results, made possible by the combination of deep isothermal water and the smooth sea surface found in the Channel, was what was possibly a unique demonstration of Lloyd mirror interference[7] in underwater acoustics.

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[6] The US Naval Electronics Laboratory in San Diego had co-operated extensively with PNL/DREP over the years. It later underwent several changes in acronym including NUC, NOSC and NRaD.

[7] A series of marked increases and decreases in sound intensity with range and depth resulting from constructive or destructive interference of the direct and surface reflected sound waves.

In the earlier years, the effort in underwater acoustics concentrated on target detection and sound propagation in shallow water. With the staff augmentation taking place in the early 1950s, a number of additional areas of interest were addressed.

By 1952, measurements had been completed on the first phase of the underwater program, designed to determine the behaviour of a sound beam projected into various types of layered ocean water. As it was by then possible to predict in a close qualitative way where the sound would go, effort was next concentrated on the second phase, which was a statistical approach to the quantitative examination of how sound at fixed ranges varied with time and depth in these same layered waters. The sheltered inside waters of the British Columbia coast were used as a model tank that provided a variety of sound velocity structures for these experiments. The only high powered sound source available initially was the Type 144 sonar[8] in HMCS CEDARWOOD. Following the lead of NRE in Halifax, this was soon augmented by the transducer unit of a Harbour Defence Sonar which was suspended at various depths below the ship. Elaborate arrays of hydrophones were constructed for receiving the

Harry Bell, Fred Sanders, Pat Nasmyth and Harry Davidson loading essentially all the Laboratory's equipment for its first sea-trial

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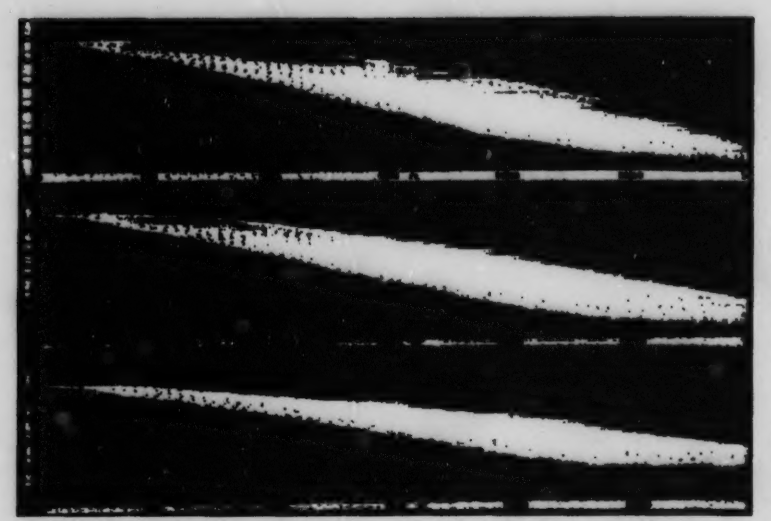
[8] The more generic term sonar is adopted rather than the term ASDIC then used in the UK to refer to their underwater detection systems.

signals below a second ship, usually CNAV EHKOLI.[9] Auto- and cross-correlation functions of the signals received at the various hydrophones were used to identify sources of fluctuations such as those arising from sound interaction with surface and internal waves. Work was also undertaken to investigate the sources and magnitudes of the errors in depth determination for the 147 (Sword) Sonar used on Canadian destroyers to set the firing depth for their Squid anti-submarine mortars. It was determined that the errors derived from a number of factors including the assumption of straight line propagation and interference from the sea surface and the ship's hull. Research was also initiated on an optical analogue—employing the refractive properties of layers of water, isopropyl alcohol and glycerin—designed to speed up the visualization of underwater sound fields.


Optical analogue - negative sound velocity gradient - three depths of sonar

Arctic Acoustics

In 1949 CEDARWOOD made a voyage to the Arctic, in the course of which she established a record in reaching a very high latitude. This was part of a joint Canada-US program including oceanography, ambient noise, acoustic propagation and reverberation, and biological studies in the North Pacific and the Bering and Chukchi Seas. Ships involved were the EPCE (R) 857, the USS BAYA and CEDARWOOD. Canadian personnel included Drs W.R. (Bill) Cameron and G.L. (George) Pickard from UBC, and Pat Nasmyth who spent part of his time on the 857 and the rest on CEDARWOOD. For the most part, the Canadian group on CEDARWOOD looked after the oceanography, while the US team conducted the acoustic and biological studies. George Pickard measured the flow through Bering Strait by mounting electrodes on the bottom and measuring the potential between them generated by the water, a conducting fluid, moving through the earth's magnetic field.

Two years later, the CGMV CANCOLIM II, a vessel purchased by DRB from the Canadian Can Company Limited—for which the vessel was named—wintered over at Tuktoyaktuk. The CANCOLIM program was the first serious oceanographic/hydrographic survey of the southern Beaufort Sea—as limited by ice—and through into the western part of Amundsen Gulf. It was important to industry because of the subsequent discoveries of oil. Due to the limited accommodation on the vessel, the participants, from POG, PNL, IOUBC, and the Department of Mines and Technical Services (DM&TS), served both as scientist and crew. Bill Cameron—on DRB staff but assigned to IOUBC as part of its

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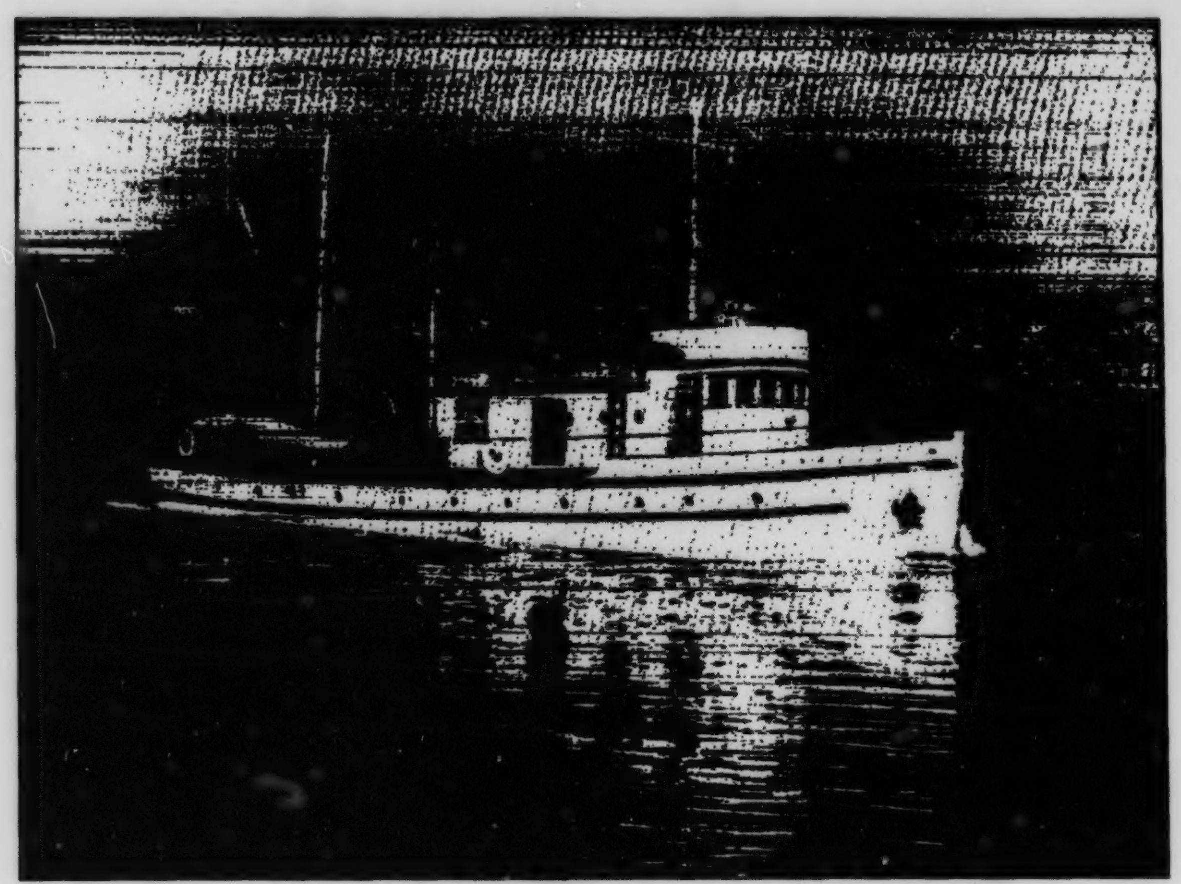
[9] EHKOLI became a Canadian Naval Auxiliary Vessel (CNAV) in 1950.



CANCOLIM II

contribution to the support of the Institute in its early years[10]—was the Senior Scientist. During the summer of 1952 and the return voyage, Pat Nasmyth was a member of the field party studying the environment. He had had considerable previous experience working in the Arctic when, as a Lieutenant in the Army, he was the navigator on OPERATION MUSKOX, an extensive snowmobile safari over the northern ice and tundra.

Two years later, PNL was to be at least peripherally involved in a follow-on survey involving POG and the USN, with Bill Cameron serving as a member of the field party on the US Icebreaker WESTWIND. It would be another five years before PNL scientists next visited the Arctic and launched what was to become one of the Laboratory's principal research activities.

Fluid Dynamics

Bob Stewart possessed a substantial background in turbulence research that led him to conclude that submarines might well be detectable through perturbations in the ocean caused by their turbulent wakes. Accordingly, the Laboratory initiated a wake detection program that had, by 1952, begun an investigation of the small-scale motions in the sea generated by the natural turbulent background against which submarine generated turbulence would have to compete. It was not until 1961 that the addition of a submarine to the Navy on the West Coast permitted the investigation of the submarine-induced signals. Fairly early on it was recognized that internal waves were another common feature of ocean waters which also held promise for submarine detection, and by the mid-1960s emphasis had begun to shift to an investigation of this phenomenon. As very little was known about either turbulence or internal waves in the ocean when these investigations began, much of the effort of the staff was of necessity devoted to the design of suitable measurement techniques and the construction of the equipment required for their implementation. Initially, effort was concentrated on the development of small, fast response flow-meters and thermometers to measure small scale velocity and temperature fluctuations in the ocean and of techniques for operating these instruments at the desired depths. Later, when the investigations turned to internal waves, a number of novel techniques were implemented for measuring their effects both from ships and aircraft. Due to the originality of the work and the inventiveness of the staff, the Laboratory developed an excellent reputation for its research in these areas of *non-acoustic* submarine detection.

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[10] The CANCOLIM survey was another substantial expression of this support.

Electromagnetics

In 1953, an experimental magnetic target was constructed to permit the evaluation of the performance of the magnetic loops laid in the approaches to Esquimalt Harbour. Preliminary measurements indicated that both the target and loops were operating well enough to justify a more detailed study. In addition, as the year closed, a model setup was being constructed on which the effectiveness of various loop configurations could be tested in the laboratory.

Materials Technology

The program in materials research was designed to deal with problems affecting the physical condition of the fleet on the West Coast. The emphasis was on rapid response, a process expedited by the desire to minimize paperwork and, as far as possible, formal chains of command. Some longer term research was also undertaken to ensure that the skills of the staff were kept up to date. This strategy was evidently successful, with continuously increasing demands for assistance and, when the crunch came, the most vociferous support for maintaining a research presence on the West Coast.

Initially, in 1950, a corrosion group was set up to search for the most effective means of employing cathodic protection and improved paint systems to prevent the corrosion of ships' hulls. By 1953, half of the Navy's active and all of its inactive ships were so protected, with none suffering a serious corrosion problem. This activity provided very active support and leadership to the Royal Canadian Navy Committee on Corrosion and Fouling (RCN/CCF), then normally chaired by the local Naval Commodore. In 1952, a metals-chemistry group was added to provide scientific facilities and technical assistance on a wide range of problems which occur in the Dockyard. Emphasis at this time was on metal failure analysis—a speciality of Ralph Barer's—and on the inspection of the welding in ships under construction: a team of radiographers from the group was quickly employed full time in this activity.

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In August 1953, Fred Sanders was transferred to Ottawa to co-ordinate all the Board's long-term projects. He was replaced as Superintendent by Mr J.S. (Stu) Johnson.

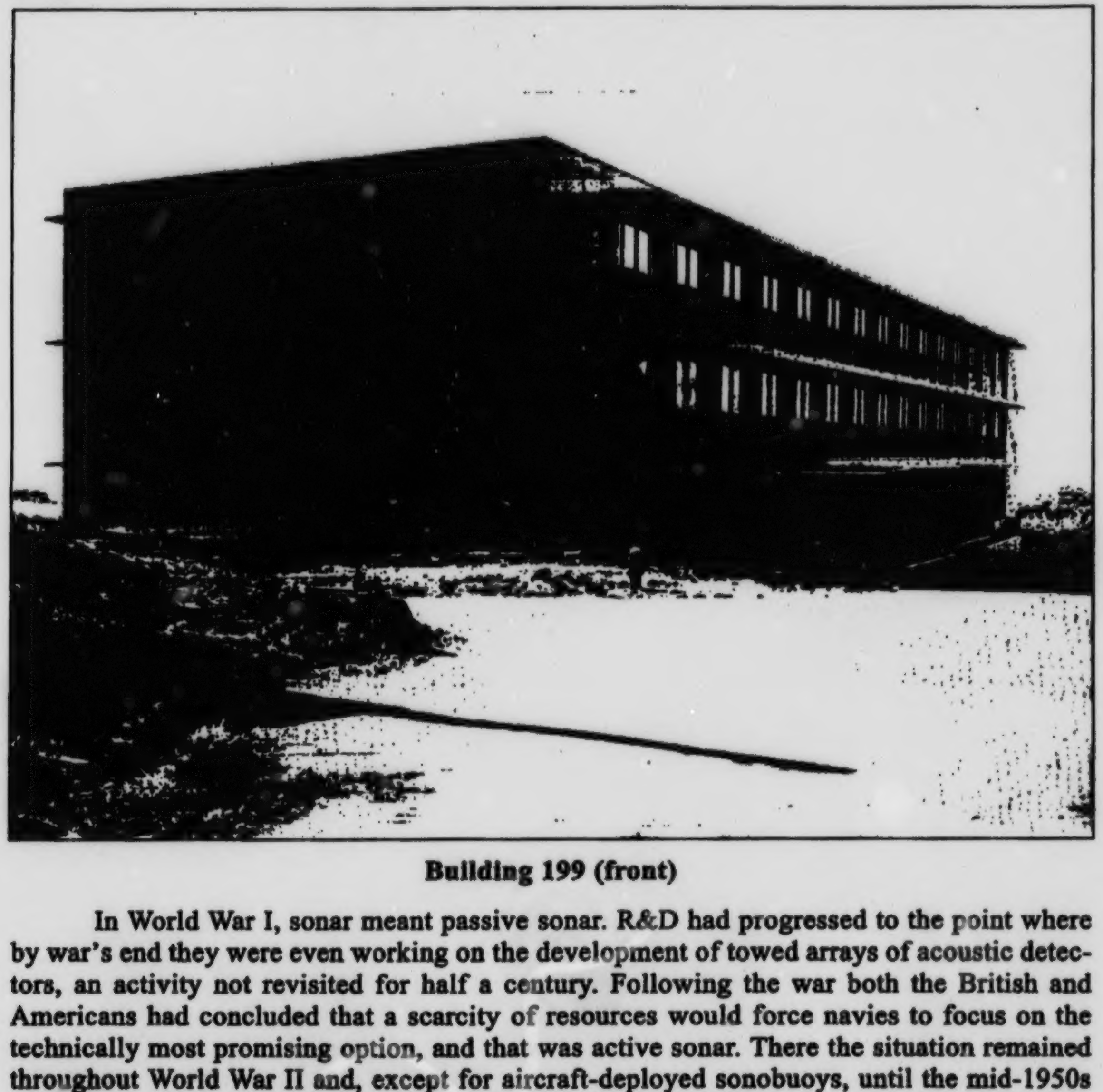
1954 to 1955 - the new building

Organization, facilities and trends

Prior to his arrival on the West Coast, Mr Johnson was the Director of Scientific Services, Navy (DSS(N)). During his first year as Superintendent, a new laboratory building—Building 199—was acquired which substantially increased the organization's ability to conduct research and respond to new requirements. The official opening ceremonies were held on 8 October 1954, presided over by the Chief of Naval Staff, Vice-Admiral E.R. Mainguy, and attended by Dr O.M. Solandt, and the members of the Board. The building was designed to hold the staff of about fifty. However, under the impetus of the Cold War, the demands for defence R&D grew apace and the resulting increase in staff soon necessitated a succession of additions to the building, the construction of a number of outbuildings, and the modification and occupancy of a number of other buildings belonging to the Base, an activity which took place intermittently over the next thirty years. The first such modification took place the next year, with the creation of a basement under Building 199 to accommodate the installation of a large low-turbulence water tunnel required for the fluid dynamics research program. Action was also initiated to provide a small building to house

Opening Building 199 - Admirals J.C. Hibbard and E.R. Mainguy, Dr Solandt (first Chairman DRB) and Mr Johnson

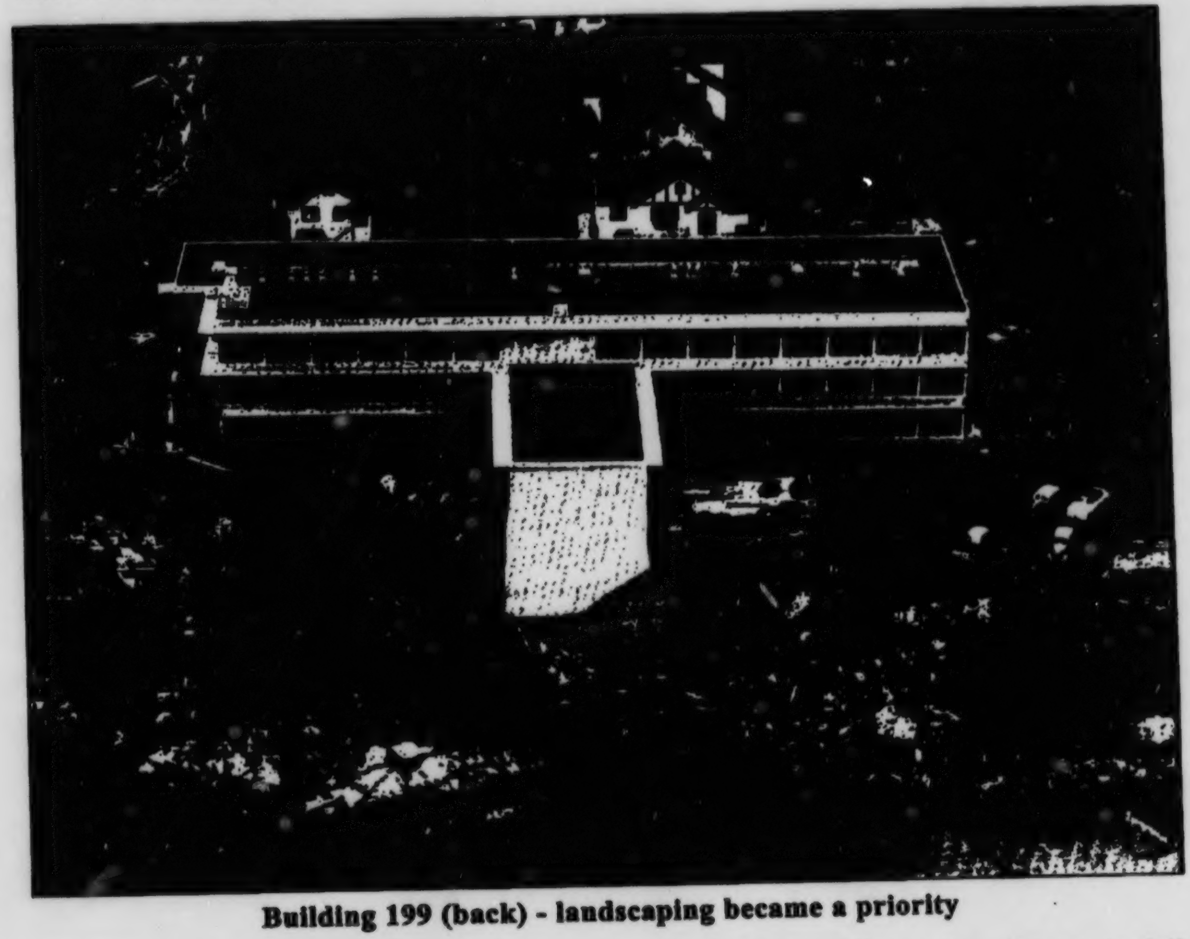
the Co-60 and X-ray radiographic equipment, both to minimize radiation hazards and facilitate the radiographic work which played an increasingly important part in the materials program.



Building 199 (front)

In World War I, sonar meant passive sonar. R&D had progressed to the point where by war's end they were even working on the development of towed arrays of acoustic detectors, an activity not revisited for half a century. Following the war both the British and Americans had concluded that a scarcity of resources would force navies to focus on the technically most promising option, and that was active sonar. There the situation remained throughout World War II and, except for aircraft-deployed sonobuoys, until the mid-1950s when the ballistic missile submarine became the target of primary concern. Monitoring this target required long-range detections in the open ocean, a task much more feasible with passive than with active sonar. This resulted in a greatly heightened interest in passive sonar in all the navies of the West, as illustrated by the development of the shore based US SOSUS passive detection and tracking system. PNL responded to the challenge by initiating research projects in low-frequency sound propagation and ambient noise, first in the Northeast Pacific and some time later in the Arctic.

The necessity to carry out acoustic experiments in deep water presented a problem as by then neither CEDARWOOD nor EHKOLI was suitable for operations in the open ocean. The situation had been recognized for some time and by the end of 1955 the design had been completed for a versatile and capable ocean-going replacement for CEDARWOOD. However, it would be several years before actual construction, so interim measures were called for. In 1955, the Flag Officer Pacific Coast made a frigate available for a PNL long-range acoustic propagation experiment and to permit POG's participation in Project NORPAC—a major oceanographic survey of the North Pacific conducted by Canada, the United States and Japan.



Building 199 (back) - landscaping became a priority

In 1954, despite a difficult recruiting climate, the staff was brought up to full strength. Maintaining it there proved, however, to be a struggle as there were several departures the following year, including that of Bob Stewart who transferred to IOUBC.[11] Fortunately, both his successive replacements, Harold Grant and B.A. (Blyth) Hughes (a summer student in 1955, made indeterminate in 1956), were already at the Laboratory. They had been recruited at the masters and bachelor levels respectively and later developed their expertise by taking doctorates in fluid dynamics at Cambridge.[12]

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[11] Although Bob Stewart was on special assignment to IOUBC, replacing Bill Cameron, he continued to be heavily involved in the PNL fluid dynamics program.

[12] From the beginning, the Laboratory took very seriously the upgrading of the educational qualifications of its staff. Under DRB/CRAD support, Pat Nasmyth, Harold Grant, Blyth Hughes, Bill Vogel, Frank Peters, John Bird, Dave Craig and Jeff Boyd obtained their doctorates, and a number of these, plus Keith Young, Dave Hopkin and Ken McRae, their masters degrees.

Ocean Acoustics

A series of five experiments concluded the measurement of sound fluctuations in shallow water as a function of source and receiver depth, receiver spacing, water temperature profile, range and frequency (8 and 18 kHz). Drs C.D. (Charlie) Maunsell and J.E. (Erwin) Lokken joined the Laboratory in 1955 to take over the analysis of the data and to conduct follow-on activities. They decided that as the frequencies of active sonars were tending to become lower, the logical next step would be to extend the investigation to lower frequencies—1.2 and 0.5 kHz. As it was desirable to increase the range in proportion to the wavelength, this necessitated transferring experiments to the open sea.

In response to the changed threat and the renewed emphasis of our allies on passive sonar, Pat Nasmyth and A.R. (Al) Milne[13] organized a new program to study low-frequency sound propagation and ambient noise in open-sea shallow water. The first propagation experiment—employing explosive sound sources—was conducted in November 1955 at the mouth of the Strait of Juan de Fuca. The program was also to include model studies of the propagation of low-frequency sound in shallow water. For this the Esquimalt Lagoon was selected as a large model tank—having a useful range of one thousand metres at a very constant depth of about four metres. Preliminary geophysical measurements were conducted to assess its usefulness to the project.

Development of the optical analogue for visualizing and computing sound fields was progressing well. Trials in calm weather on CEDARWOOD and a frigate, followed by trials on the frigate in rougher conditions, indicated satifactory stability of the layers under all the conditions encountered. It was therefore decided to increase the effort on the analogue with the objective of having at least two models available for use in an escort by Navy personnel.[14]

Bob Stewart operating a Kelvin Sounding Machine to make oceanographic measurements from CEDARWOOD

Fluid Dynamics

For the early years of the program the development of suitable instrumentation became the primary preoccupation. Water tunnels were required for the development and calibration of the environmental sensors. One was borrowed from the David Taylor Model Basin (DTMB) in Washington DC as an interim measure while a larger low-turbulence unit, whose specifications were drawn up by Bob Stewart, was being constructed in Germany. Having successfully completed its acceptance trials—it achieved a turbulence free speed of 23.5 knots, twice the design speed—it arrived from Germany in September 1955 for installation in the recently expanded basement. This was the main activity for some time; the departure of Bob Stewart to IOUBC and of Harold Grant to Cambridge to work on his doctorate,[15] plus competing demands on the staff from the higher priority acoustic projects, left little effort for field trials.

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[13] Recruited from NRC.

[14] Although the development of the analogue progressed well and excited considerable interest, it, along with a number of other analogue ray tracing devices under development in other laboratories, was soon to be replaced by the digital computer.

Electromagnetics

Pat Nasmyth's examination of the noise background of the harbour defence loops at Albert Head indicated that he was looking, at least in part, at the natural fluctuations in the geomagnetic field. Thus was born the Laboratory's interest in electromagnetics, followed shortly thereafter by the development of a major research activity. The program, augmented by the services of Dr H.J. (John) Duffus, Al Milne, and J.A. (Art) Shand, now grew to include the evaluation of the magnetic loop system laid by the RCN at Esquimalt. Sensitivity measurements were carried out on all the loops of the system, with the magnetic dipole target as standard, and the results related to actual detection performance by direct comparison of the signal of the target with those of several small steel ships. The development of an improved indicator loop system was then addressed, with several loop configurations being studied both theoretically and by model experiments. The results showed how worthwhile gains could be achieved with the existing system, without appreciably increasing cost or complexity. As geomagnetic fluctuations constitute the noise background against which targets are to be detected and as they cannot be removed by filtering, a knowledge of the nature of such fluctuations—with periods ranging from seconds to minutes—is of major importance in loop design. Thus a scientific study of their origins and characteristics was initiated.

Materials Technology

The work in the section now encompassed five technical areas, some closely interrelated: analytical chemistry, physical metallurgy, nondestructive testing, anti-corrosion and paint. The first three were set up primarily to provide scientific facilities and technical assistance in problems arising in the Dockyard. The last two provided scientific advice and carried on research into more efficient methods of preventing corrosion and improving paints and their application. To cope with these responsibilities and to increase the research capability of the Section, several scientists were recruited, including Messrs C.A. (Clint) Waggoner (organic chemistry), R.H.B. (Dick) Sewell (inorganic chemistry), J.R. (Ray) Brown (paints), and B.F. (Frank) Peters (metallurgy and NDE). All were to have a very considerable impact on the development of the materials program and its interaction with the Canadian Forces. It was at this time that Ralph Barer started the Vancouver Island Chapter of the American Society of Metals, which held regular meetings in the Dockyard with Naval support staff. In addition, he and Frank Peters provided courses on radiography, in cooperation with the Department of Mines in Ottawa.

The capabilities of the section were increasingly being recognized with requests for assistance rising 40% from 1954 to 1955, from a commendable 550 to 790 per year. In nondestructive testing, emphasis shifted from radiography of welds on ships under construction—the hulls now being largely completed—to examining the welding in other ships of the fleet. There was also much increased interest in preventative maintenance on items such as cylinder liners and crankshafts. In anti-corrosion, much of the effort was devoted to consulting and the education of naval personnel, so that they could take over the bulk of the responsibility for corrosion prevention of the hulls of both the active and inactive ships.

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[15] From September 1954 till September 1957.

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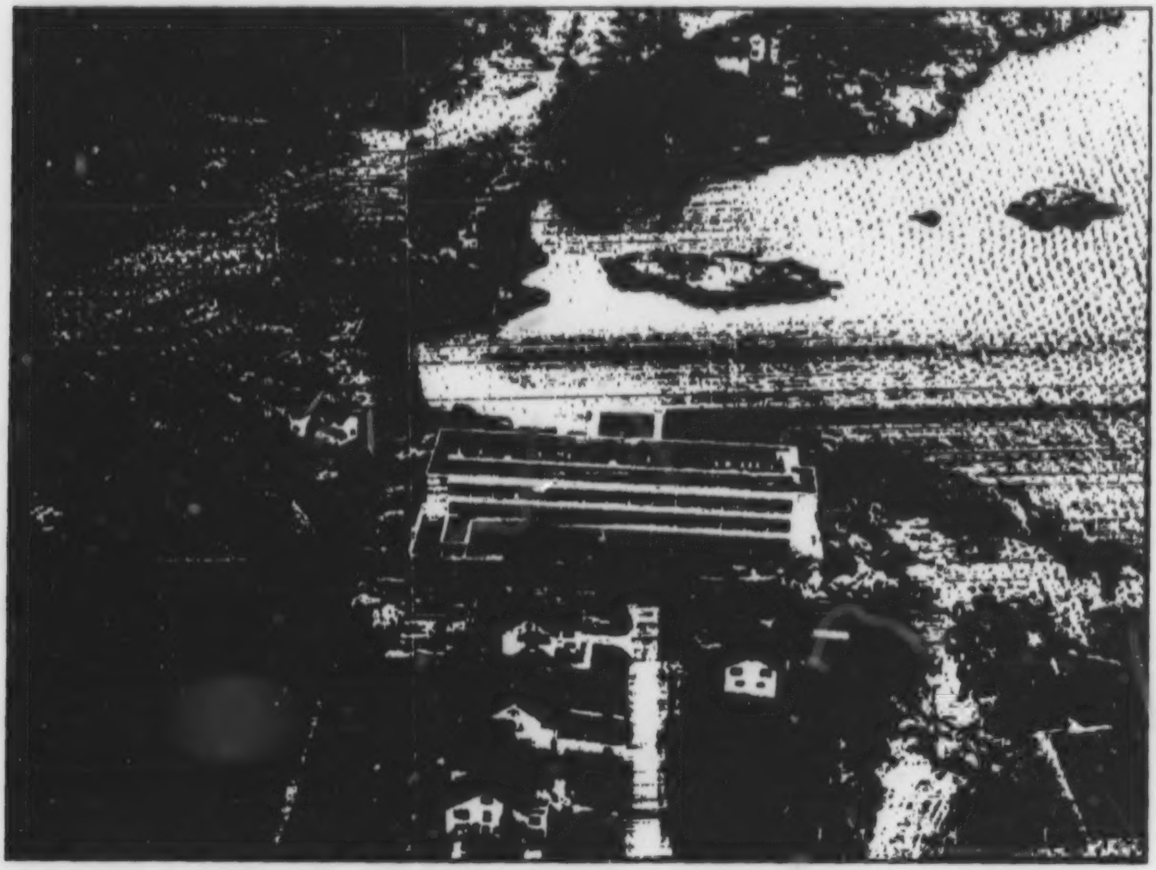
In September 1955 Stu Johnson returned to Ottawa to become the Executive Assistant to the Chief Scientist DRB/HQ. He later served as the research member on the Canadian Joint Staff in Washington. He was replaced as Superintendent of PNL by Dr W.L. (Bill) Ford.

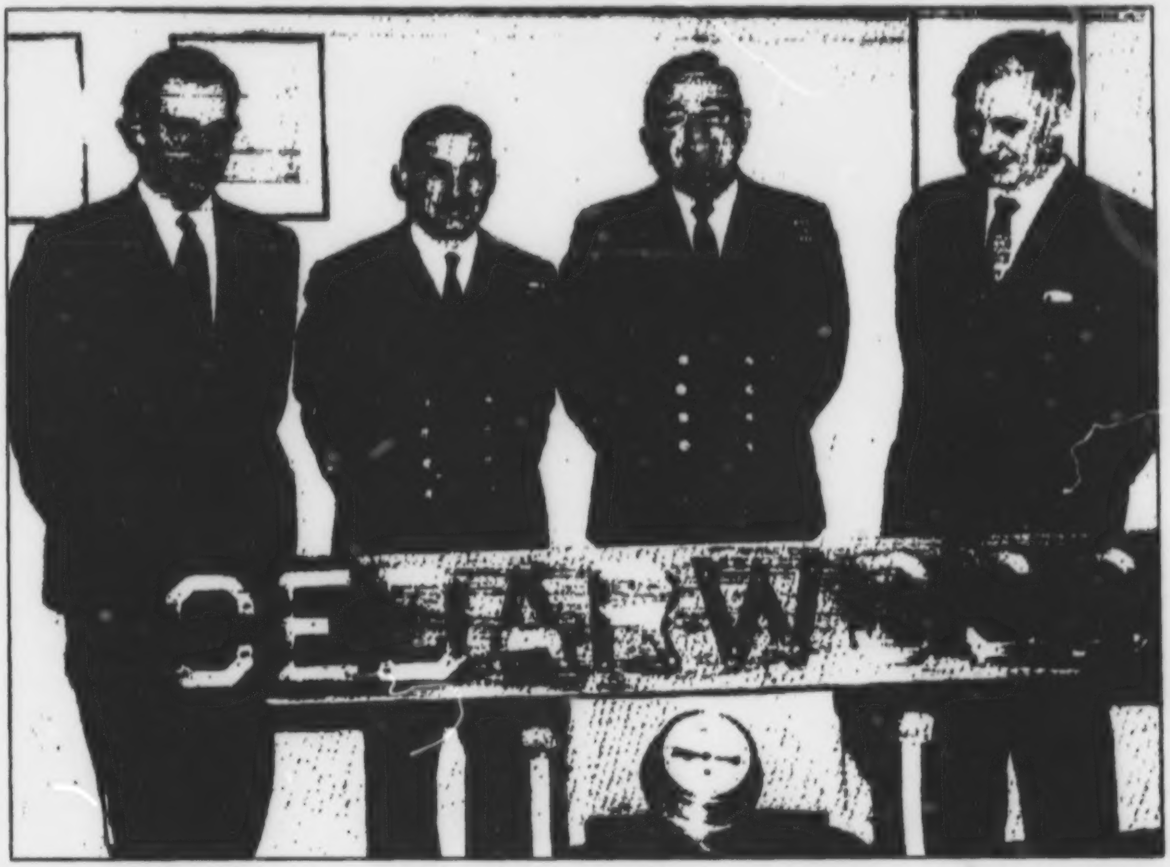


Aerial view of Building 199. The low peaked-roofed structure to the left was originally the Pigeon Loft associated with the Base Message Centre; the louvres at the top were to permit the entry of carrier pigeons. At the time of the photograph, the building was occupied by the Base Chaplain. Later it was destroyed and the land converted to a parking lot. In the left foreground is the playing field.

1956 to 1959 - PNL - research ships replaced - increased interest in the Arctic

Organization, facilities and trends

Dr Ford's background and training were in oceanography. Before coming to PNL, he was in succession, the Head of Acoustics at NRE, then on course at the National Defence College (NDC) in Kingston, and finally the Director of Scientific Services, Navy (DSS(N)) at NDHQ. This provided him with an excellent background for managing a laboratory devoted to maritime research. During his time at PNL, an interim solution to the ageing research ship problem was implemented, the electromagnetics program expanded and there was greatly renewed interest in research in the Arctic.

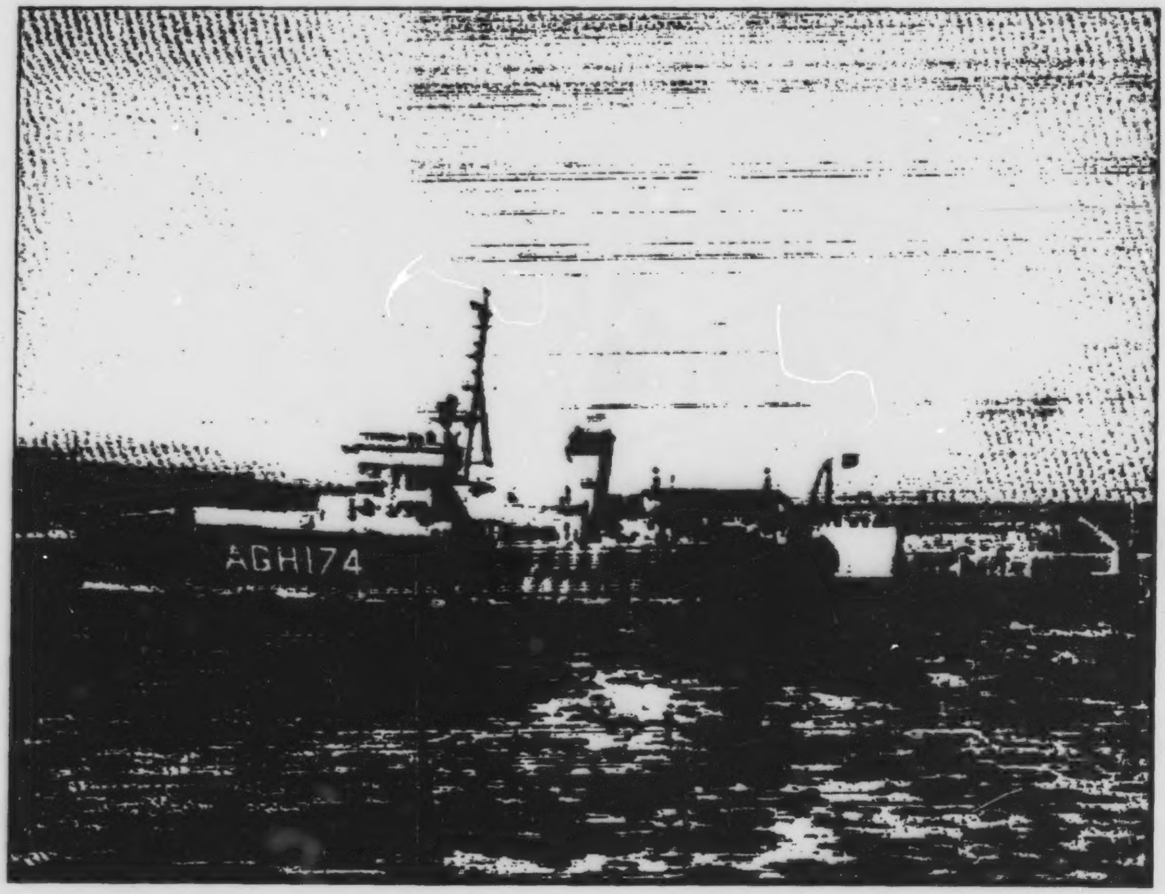


Dr Ford, Capt (N) Pierson, Cdr Hall and Dr Tully - presentation of CEDARWOOD nameplate to Dr Tully

Because the existing research ships were not able to operate in the open ocean, the Flag Officer continued to provide other more-capable vessels from his fleet to permit meaningful research programs for both PNL and POG. In 1956, frigates were provided for five long-range propagation experiments by PNL and for a six-week NORPAC survey by POG. The following year there were an additional thirteen cruises involving Naval and auxiliary vessels not normally available for research. Although attesting to an extraordinarily close working relationship between West Coast scientists and the Navy, this mode of operation was clearly unsustainable as these resources were provided by the Flag Officer at the expense of his regular training and operational schedule.

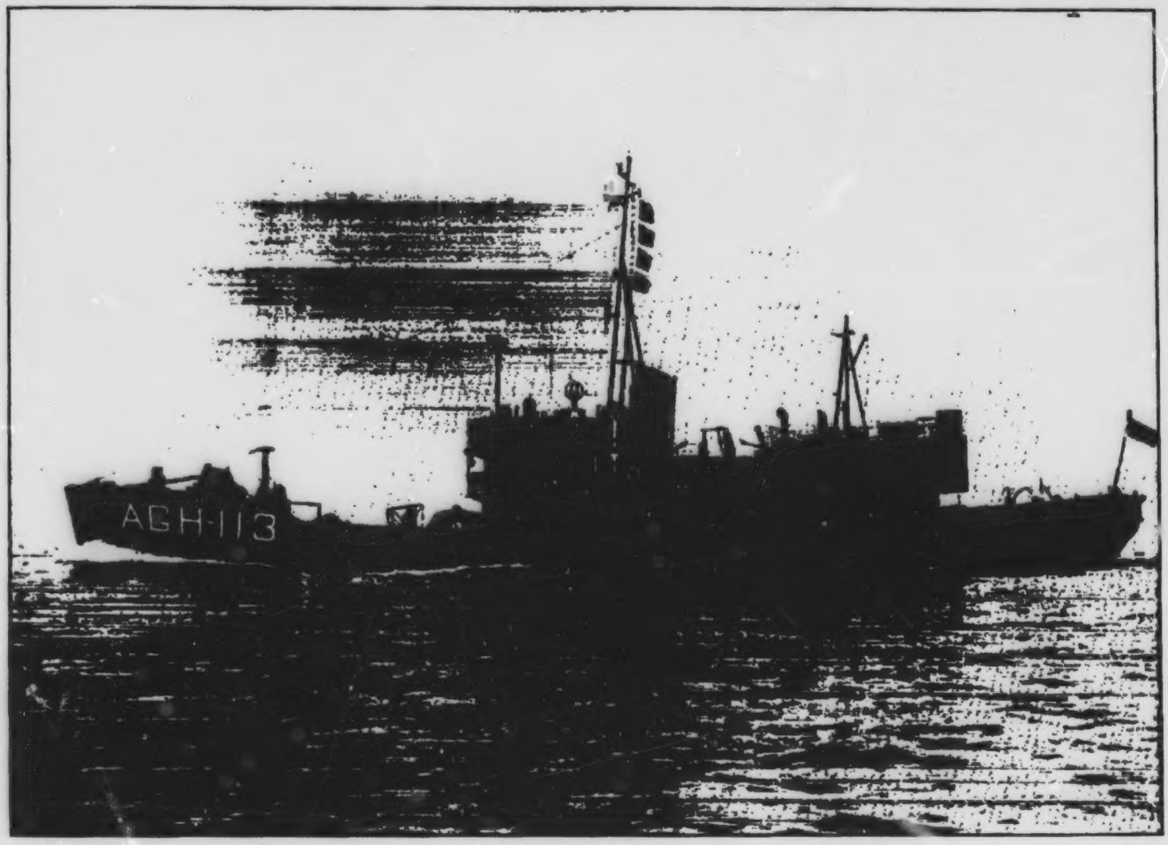
The problem was addressed by replacing the current research ships with more seaworthy vessels. In October 1956, HMCS CEDARWOOD was decommissioned and replaced by the ALGERINE Class, minesweeper HMCS OSHAWA. OSHAWA turned civilian in November 1958. In the same year, EHKOLI was turned over to DM&TS for use by IOUBC. It was replaced as a second ship by CNAV WHITETHROAT—built as a mine layer. Both OSHAWA and WHITETHROAT had undergone extensive conversions, including the installation of the laboratories and deck machinery required to make them well suited to underwater acoustic and oceanographic research. By this time, all the West Coast research ships had become civilian manned and controlled, thus marking the end of a decade of a close, friendly and fruitful working relationship between, on the one hand, the Naval Officers and Men who served in the research ships and on the other hand, the sea-going scientists.

The principal West Coast research vessels were at this time provided by the RCN and scheduled by PNL to meet the research needs of PNL, POG, and IOUBC. To ensure the equitable and efficient utilization of the ships, a committee of representatives from each of



OSHAWA

the above organizations and the Navy was set up. To cope with the demand for ship time, the users had become adept at the quick turn-around, thus maximizing the time at sea. This resulted in OSHAWA and WHITETHROAT being among the hardest worked ships in the Command; in 1959, for example, OSHAWA made a total of 24 cruises totalling 207 days and WHITETHROAT, 22 cruises totalling 161 days.



WHITETHROAT

Ocean Acoustics

The sound fluctuation studies were now moved to the deep waters of the Gulf of Alaska where the underwater sound velocity versus depth profile is unusually conducive to effective sonar performance, there being two sound channels both of which are close enough to the sea surface to be accessible to towed sonar. The occurrence of this condition makes the waters of the West Coast sufficiently different from those in other ocean areas that it provided much of the technical rationale for maintaining an ocean acoustic program on the West Coast. In the mid-to-late 1950s, experiments were carried out to study the acoustic characteristics—including convergence zone propagation—of the Alaskan Gulf in order to estimate potential sonar performance in this area. Although the primary motivation for the fluctuation work was active sonar, the frequency range of the measurements was extended low enough to ensure that the results would also be applicable to passive sonar. A separate series of experiments was also conducted in the approaches to Vancouver Island to measure low-frequency ambient noise, and the propagation losses suffered by sound going from deep to shallow water. To operate at the lower frequencies, improved instrumentation and measurement and analysis techniques were required. On one operation, in 1959, telemetering from remote hydrophones suspended from a skiff showed major improvements in noise level and useful range compared to those obtained by suspending hydrophones directly from the research ships. This was the first in the development of a series of remote recording and telemetry systems which proved indispensable to the Laboratory's increasing number of low-frequency acoustic investigations. A second advance, which occurred the same year, was the introduction of a digital computer to facilitate the processing of acoustic data, some of which had been accumulated over the preceding several years. A dramatic improvement ensued; the digital computer had come to stay.

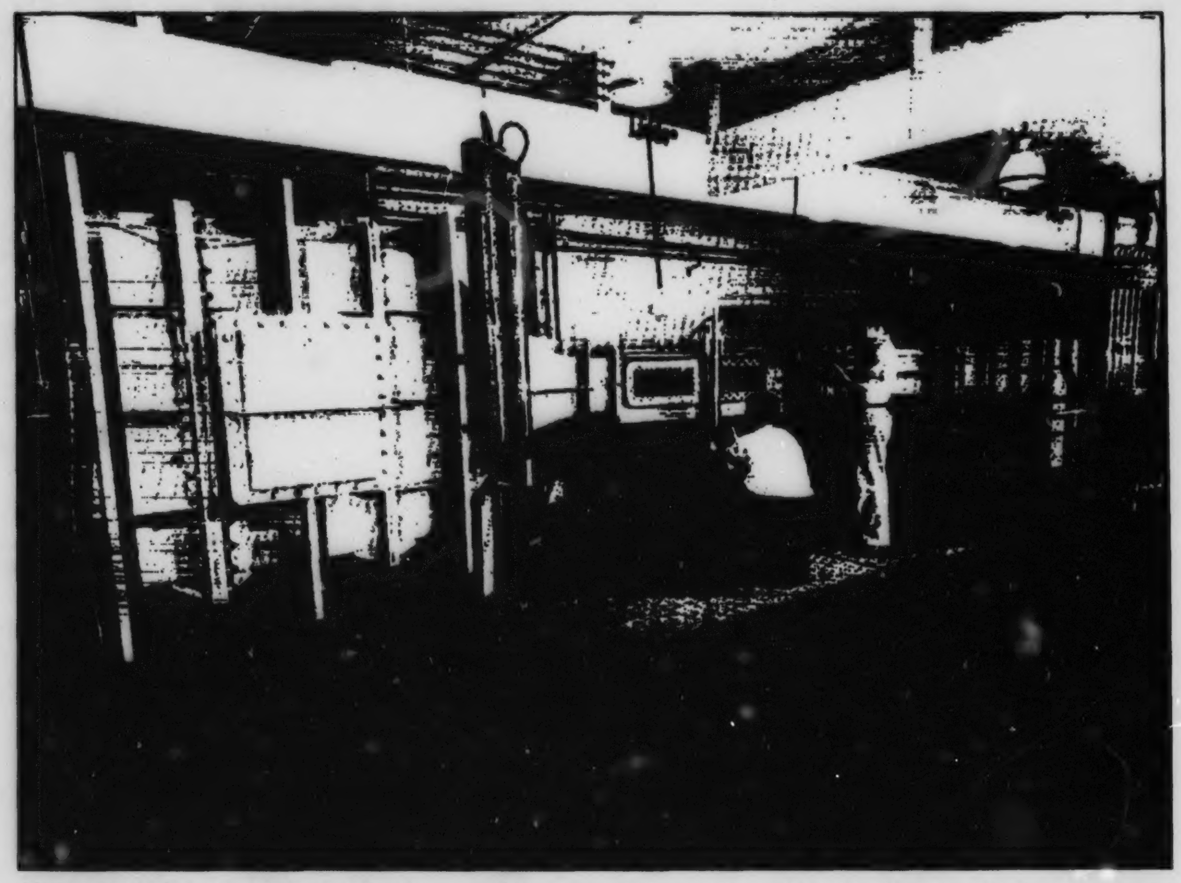
In order to investigate, in a relatively controlled setting, the mechanisms involved in low-frequency sound propagation, scale model experiments were carried out in the Esquimalt Lagoon. This phase of the program was taken over by Dr J.A. (Joe) Scrimger who, from his arrival at PNL in June 1956 until his exchange posting to Hudson Laboratories five years later, investigated modal propagation, particularly as influenced by surface waves. His paper on this subject is still often quoted.

Arctic Acoustics

In 1958, the US submarine Nautilus sailed under the Arctic ice cap, thus demonstrating that as far as the ballistic missile threat was concerned, the country had just acquired a third ocean. Fortunately, PNL scientists had just produced a proposal for an extensive underwater acoustic measurement program for the Arctic, and hence were well placed to respond to this development. This made it possible to launch, in March 1959, the first in a series of under-ice acoustic experiments to measure sound propagation and ambient noise in areas of potential operational interest. The measurements, carried out in Barrow Strait under first-year, shorefast ice, indicated that the sound propagation and ambient noise conditions were such that submarine detection in the Arctic channels might well be feasible. Demonstrating this in quantitative terms was the primary focus of the PNL Arctic acoustic research program for the next two decades. In carrying this out, an enviable expertise was developed on how to survive and operate successfully in this most hostile environment. This involved the design of clothing and shelters, techniques for drilling holes through the ice and grooming runways on ice floes, and the development of specialized equipment and techniques for making acoustic measurements in unique circumstances. This expertise not only proved essential to the Canadian military in devising strategies for Arctic surveillance, but became a key factor in the development of co-operation with the various US laboratories concerned with the same problem.

Fluid Dynamics

The low-turbulence water tunnel became fully operational in 1956. Work then began on the development of instrumentation and measurement techniques and on studies of pressure fluctuations in the turbulent wake of a cylinder and on the wake of a self-propelled body. The tunnel also proved to be useful in other of the Laboratory's programs. After having applied considerable effort to making it quiet acoustically, it provided some useful empirical work on the noise in towed hydrophones. It also was used for testing sea-going gear and modelling. Examples of the latter were scale models of a towed 8-kHz projector for the sound fluctuation project and various components for a water tunnel being designed for testing paint panels. Due to these activities and staff changes, the environmental measurement program was largely in abeyance until Harold Grant's return from Cambridge in September 1957. Effort was then concentrated on the measurement of the intense turbulence found in Discovery Passage. Measurements were made of the spectrum of the turbulent energy as a function of eddy size, for comparison with theoretical forms available in the literature. As this had not been done before, the measurements made in 1959—and again in 1962—excited considerable interest internationally.



Tony Moilliet and Blyth Hughes making measurements with the low-turbulence water tunnel

Electromagnetics

The investigation of the performance of harbour defence loops having revealed the necessity for a more detailed examination of the characteristics of the electromagnetic background and their relation to fundamental processes taking place in the ionosphere, the question arose of how to satisfy this requirement. During a number of visits to USNEL and the Marine Physics Laboratory (MPL) in San Diego, Pat Nasmyth had become acquainted with Sir Charles Wright and, knowing his past and continuing interest in electromagnetic and geomagnetic phenomena, being aware of his tentative plans to retire (again) to his former home in Esquimalt, and suspecting strongly that he would not be able to stand an inactive retirement for more than two weeks, let him know that there would be a contract ready for him at PNL should he feel restless.

A brief perusal of Sir Charles' resume shows why he was an odds-on favourite to have a profound influence on the PNL research program. He was a graduate in physics and mathematics from the University of Toronto, where he acquired a lifelong interest in the geophysics of the upper atmosphere, particularly on the effects of penetrating radiation or cosmic rays. He continued his studies in this subject at the Cavendish Laboratory of Cambridge University, then applied for and was accepted for the position of geologist on the Scott Antarctic Expedition of 1911. He achieved considerable recognition on this expedition both for his scientific discoveries and the fact that he was the navigator who located Captain Scott's tent following the tragedy. In the first world war, he served with distinction as an officer of the British Army working on the development and exploitation of wireless techniques, for which he was twice mentioned in despatches and awarded the Military Cross and the Medal of Chevalier of the French Legion of Honour. For his work as Staff Officer in Wireless Intelligence with the General Staff, he was made an Officer of the Order of the British Empire (OBE).

Following his service in the first world war, he continued his interest in military matters by joining the Admiralty Research Department as assistant to its Director. In 1929, he was appointed Superintendent of the laboratory at Teddington. In 1934, he became Director of Scientific Research, a position he held throughout the war. In this capacity, he played a major role in the development of radar. He was a splendid organizer and early in World War II persuaded his contacts at the University of Toronto to initiate a program to train radar officers for service in the Royal Navy. Officers from this program served on most of the RN's capital ships; after the war many of them pursued substantial military or scientific careers in Canada.

In 1946, the Royal Navy Scientific Service (RNSS) was formed with him as its first Chief. In the same year, on being awarded the honour of Knight Commander of the Order of the Bath (KCB), he became Sir Charles Wright. A year later, at age 60, he left the RNSS and became the Scientific Advisor to the British Joint Services Mission in Washington. In 1951, he purchased a house in Esquimalt but spent little time there as he soon became the Director of the Marine Physical Laboratory at Scripps Institute of Oceanography in San Diego, a position which he held until 1955.[16]

He then returned to Esquimalt and, as predicted, lost little time before turning up at PNL to arrange for a contract to study the geomagnetic fluctuations which affect submarine detection by electromagnetic sensors. In this capacity he carried out a number of experiments using facilities spread around the globe, expedited in large part through the many influential contacts which he had established over the years, and by the respect with which he was held. His boundless curiosity, enthusiasm, and energy led to widespread co-operation with a number of foreign and domestic institutions, including Scripps, Stanford, McGill, UBC and several others referred to later in this report.

In 1957, a large experimental array was installed on the shore at Albert Head to investigate the electromagnetic micropulsations which affect the performance of harbour defence loops. In 1958, an ambitious program was launched to examine the geographic extent of these micrpulsations—0.001 to 3 Hz—and their cross-correlation over a wide range of sensor separations.

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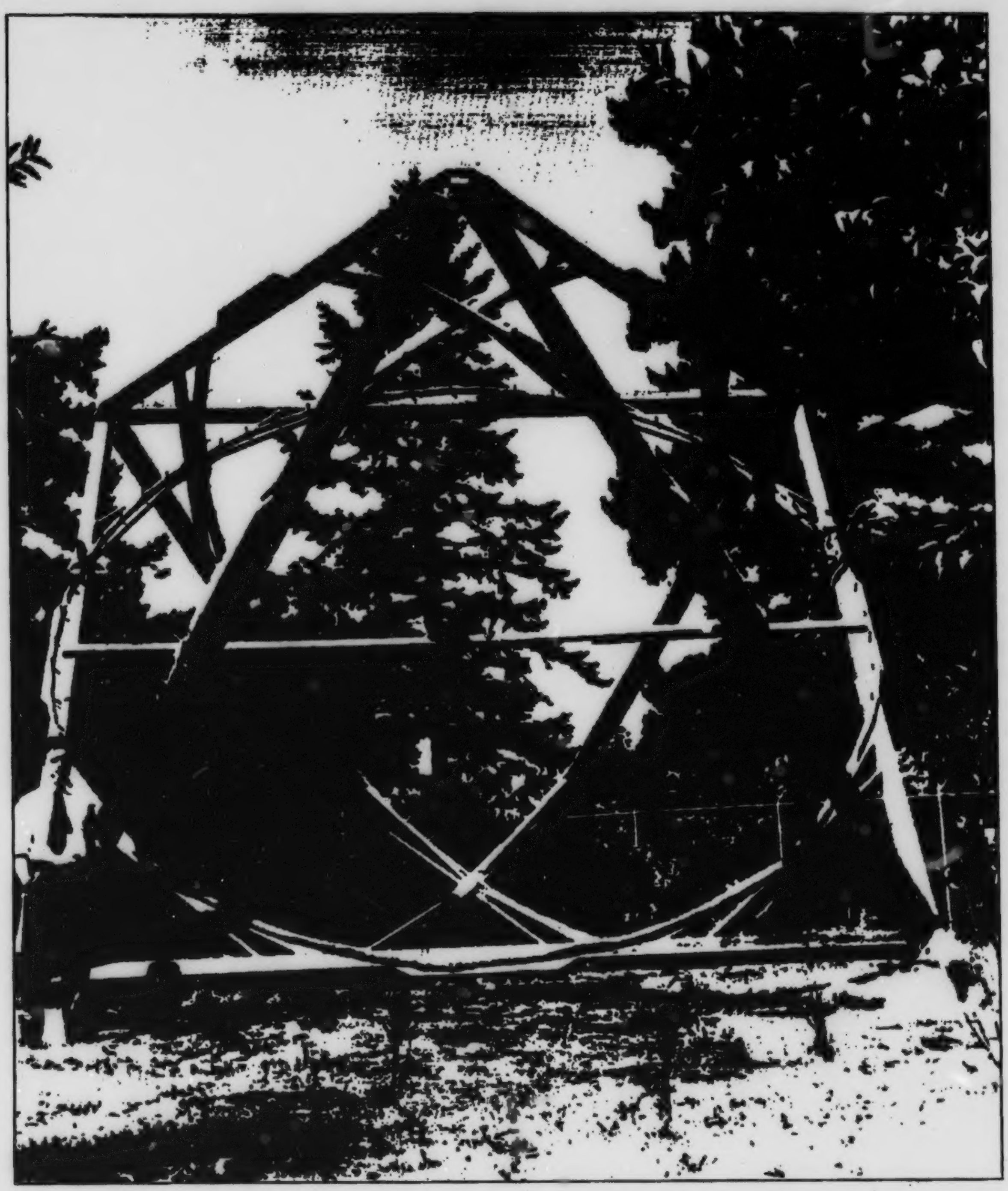
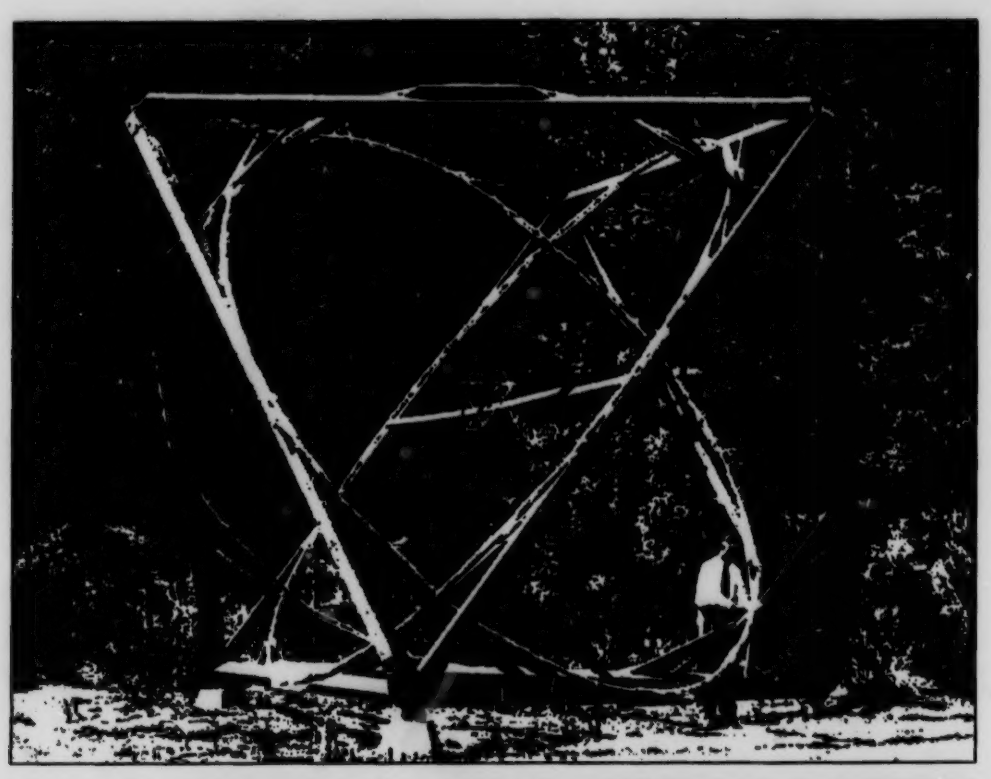
[16] The details of Sir Charles career before his arrival at PNL are taken largely from the biography co-authored by his daughter Pat. "SILAS—The Antarctic Diary and Memoirs of Charles S. Wright," edited by Colin Bull and Pat F. Wright. Ohio State University Press (1993)



John Duffus stands next to his and Art Shand's creation, the electromagnetic array at Albert Head



(Top) Art Shand working on the array. (Bottom) Art and John Duffus in the Penelope fitted out as a dipole source for monitoring the performance of the Navy's harbour defence loops at Albert Head.

Using the Albert Head installation as the reference point, measurements were made at ever increasing distances: 1 km at Albert Head in March; 7 km at William Head in April and May; 45 km at Bear Creek, also on Vancouver Island, in May and June; 300 km at Summerland in the Okanagan in July; 940 km at Ralston, Alberta,[17] in October; and 1750 km near Borrego Springs, California, in February 1959.

The greatest differences were found at the California site, which was attributed to its much greater distance from the auroral zone. Anomalous behaviour was also observed, most noticeably at those sites close to the sea, due to changes in electrical conductivity arising from local variations in geophysical properties. An investigation of this phenomenon began with measurements at pairs of stations separated by distances from 0 to 45 km at Ralston, earlier experiments having shown that this area, situated over a homogeneous geological structure, was almost free of conductivity anomalies and hence would be representative of the unperturbed case. The next step was to carry out an experiment in an area with gradients or discontinuities in conductivity. As a seacoast presents such a non-uniform structure, an experiment to measure the effect of proximity to the sea was then carried out. This called for a sharply defined seawater-land interface of simple, known configuration in a region free of topographical features. No such ideal site was accessible but the delta and lower valley of the Fraser River were considered to approach this requirement. Accordingly, PNL set up a detector array on Westham Island just inside the dike. The other station was established by UBC at Abbotsford, about 60 km from Westham Island. This activity opened up a promising line of inquiry, both experimentally and theoretically, first at PNL, then at Royal Roads, UBC, and UVic. In fact, research on this subject at the latter institution, involving field trials, scale models and theoretical studies continued into the 1990s.

The scientists involved in the micropulsation studies at this time were Sir Charles, Pat Nasmyth[18], John Duffus,[19] Don Evans and Art Shand.

Materials Technology

During this period the staff continued to address an increasing number of day-to-day requests for assistance, a number of which were associated with the teething problems of the recently completed destroyer escorts. Also research projects were initiated to develop specific laboratory techniques and procedures to meet the growing demands from ship and shore units.

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In August 1959 Bill Ford traded positions with Fred Sanders—then Scientific Advisor to the Navy—and returned to Ottawa. He later became the Director of Personnel at DRB/HQ, following which appointment he replaced Bill English as the Director-General of BIO.

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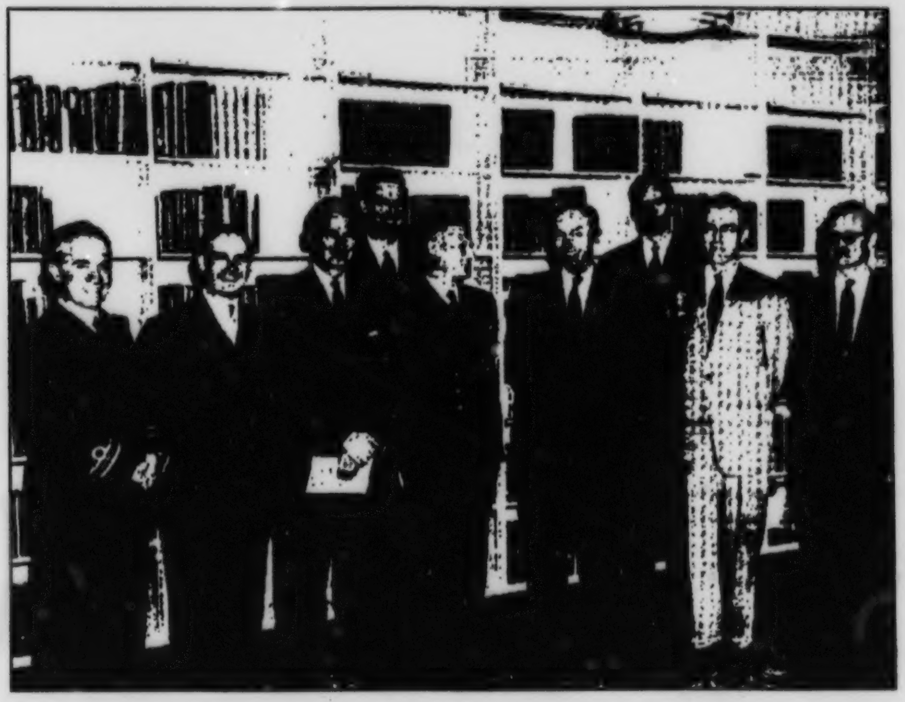
[17] A trials area of another DRB laboratory, the Suffield Experimental Station (SES). It later became the Defence Research Establishment Suffield (DRES).

[18] At the end of 1958, Pat left to become the Director of Scientific Services at RCN/HQ in Ottawa. The next year he became the Director of Maritime Research at DRB/HQ. He was appointed Deputy Research Member to the Canadian Joint Staff in Washington in 1963, and in 1966 returned to Ottawa as the Director of Physical Research.

[19] In the fall of 1959, John left to join the Physics Department at Royal Roads Military College; he later became the Dean of Science and Acting Principal. For several years after his departure, he continued to co-operate with PNL scientists and Sir Charles in the conduct and reporting of the micropulsation studies.

During Dr Ford's time as Superintendent there were a number of visits by senior members of the UK defence establishment. Lord Louis Mountbatten touring the Laboratory with Bill Ford (top), and being introduced to Harold Grant (bottom).



Sir Alec Douglas-Home and party touring PNL. In October 1963, he became the prime minister of the UK.

Earl of Selkirk and party. Bill English on far right, Ashton Patterson at back.

Right Honourable Aubrey Jones and party. Admiral Rayner, third from left. Dr Ford and Sir Charles on the right.

(back) F. Rowe J. Jarvie B. Hughes R. Temple J. Scrimger E. Silver
(front) D. Tweedhope D. Walton T. Hardy F. Peters H. Grieve

1960 to 1966 - a purpose-built research ship - electromagnetics goes global

Organization, facilities and trends

The growth in the staff continued; by the time that Fred Sanders left the Laboratory for the second time, in 1966, the number had reached one hundred, double that existing at the time of his earlier departure, thirteen years earlier. Thus once again he experienced crowded quarters and was the one to take the steps to alleviate the problem, much to the benefit of his immediate successors. By the time he left, construction had started on a major extension on the north side of Building 199, which was to include laboratories and offices for electromagnetics, conference rooms and receiving stores.

Dr Sanders

In 1962, Bill English, who had been the section head responsible for the ocean physics projects, left to become the first Director-General of the Bedford Institute of Oceanography. The areas of his responsibilities were then split, with the projects in underwater acoustics and fluid dynamics, and those in electromagnetics being taken over by Harold Grant and by Dr S.Z. (Stan) Mack respectively.

Activity continued towards replacing OSHAWA as the senior research ship on the West Coast. Near the end of 1962, final authority was granted and a contract placed for the construction of the new research vessel—CNAV ENDEAVOUR—a twin-screw diesel-electric ship, 235 feet in length, capable of speeds up to 16 knots and with an endurance at economical speed of 8,000 to 10,000 nautical miles. She was to be equipped with generous laboratory space, extensive gear-handling equipment and capable of carrying a small helicopter. Construction began early in 1963 at Yarrows Limited[20] in Esquimalt. The ship was accepted into service in March 1965. Dr A.H. Zimmerman, the second Chairman DRB, said of this occasion:[21]

> The acceptance of CNAV Endeavour is a memorable occasion for the Defence Research Board. CNAV Endeavour is the first ship especially designed and constructed by the Department of National Defence for research at sea.
> She is not the first ship of this name nor the first Endeavour to be commissioned for scientific purposes. In 1768, Capt James Cook in HMS Endeavour was appointed to conduct an expedition to observe the transit of Venus and to carry out geographical researches in the South Pacific Ocean. The complement of Endeavour included several men of science, notably Sir Joseph Banks, later president of the Royal Society. The expedition covered the period from July 20, 1768, to July 13, 1771, and returned to England after an historic cruise.
> Defence science has become an intimate and essential partner in all spheres of military operations and planning. The research and experiments that this ship can now make possible will, without doubt, improve and increase the effectiveness of ships of the Royal Canadian Navy and of the NATO alliance.

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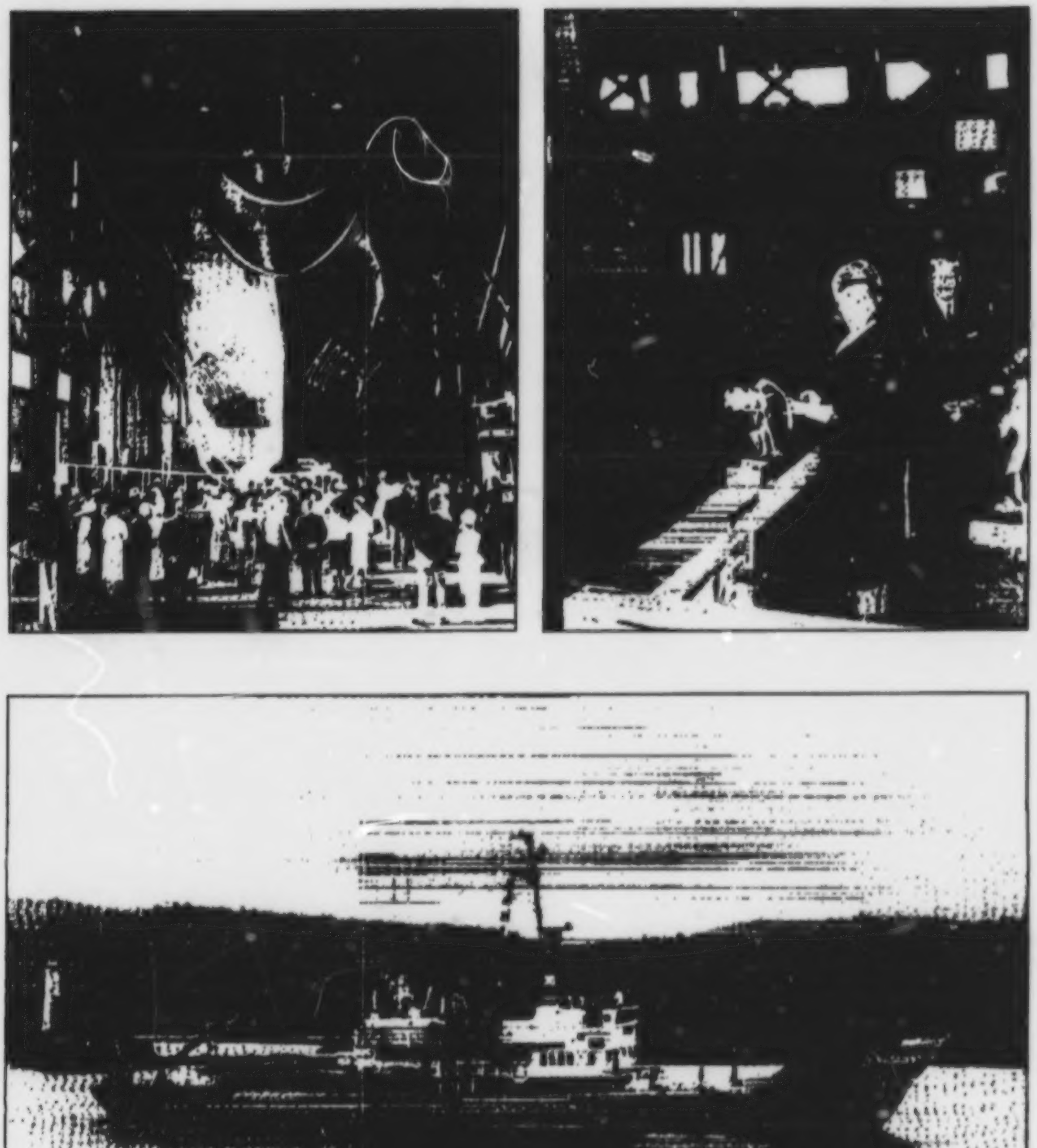
[20] The shipyard, strategically located in Esquimalt Harbour close to HMC DOCKYARD, was, since 1894, closely associated with the Royal Navy, the Royal Canadian Navy and various government departments. It repaired and refitted many Royal Navy ships prior to the formation of the Royal Canadian Navy in May 1910 when Canada took over the Pacific naval establishment, and in the 1914-1918 war continued this close association. During World War II Yarrows delivered to the RCN seventeen frigates, five minesweepers, and two landing-craft. After the War they converted and built destroyers, and repaired and refitted many navy ships, including ENDEAVOUR. The shipyard closed in 1995 thereby ending yet another chapter of West Coast maritime history.

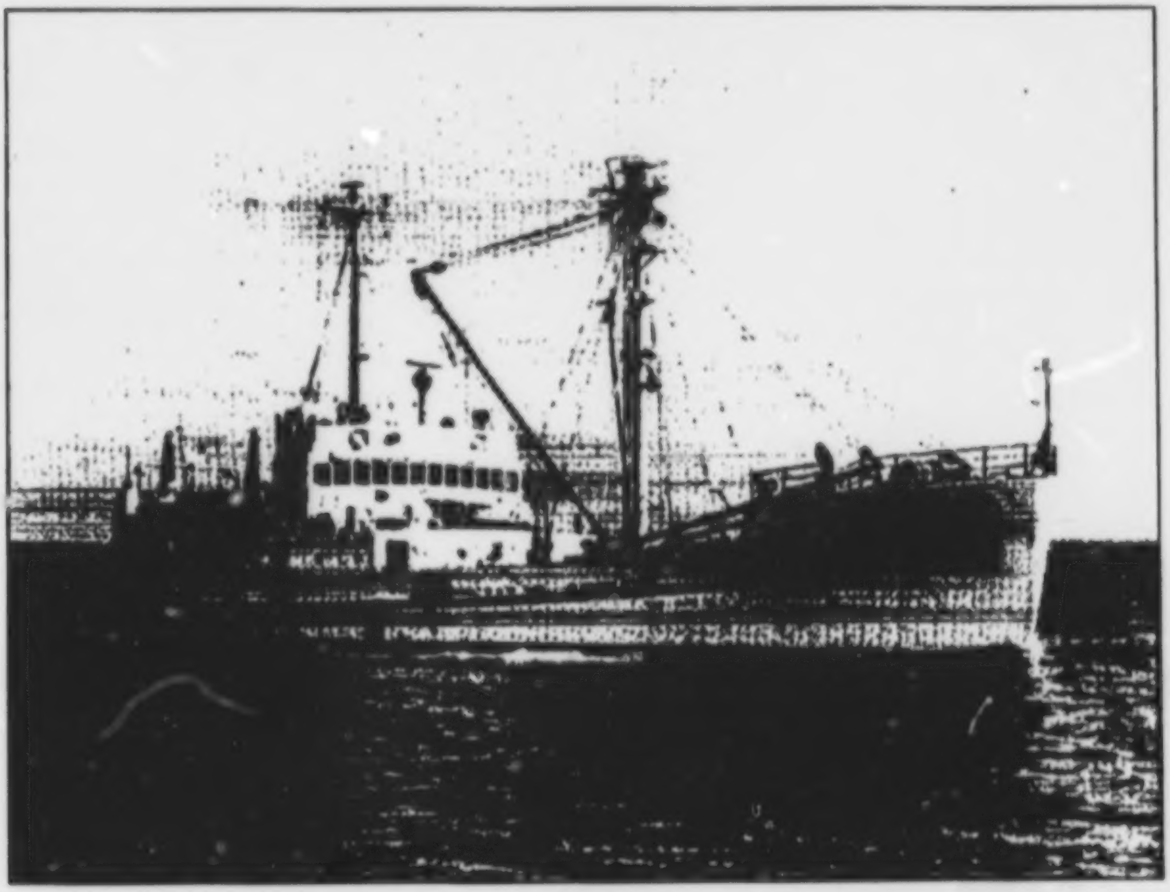
[21] Preface to DND Commemorative booklet, "CNAV ENDEAVOUR – AGOR 171 – Oceanographic Research Vessel." Roger Duhamel, FRSC, Queen's Printer and Controller of Stationary, Ottawa, 1965.



(top) Mrs Zimmerman launching CNAV ENDEAVOUR, Dr Zimmerman looking on. (bottom) ENDEAVOUR, final configuration 1994.

Initially there were some teething problems The vessel showed a tendency to roll rather heavily in steep waves, a problem eliminated by the retuning of the anti-rolling tanks[22] and the addition of bilge keels. Additional problems associated with shaft vibrations at high speeds and with pounding of the bulbous bow in heavy seas were addressed in due course resulting in a vessel that provided excellent service to the Laboratory and other West Coast research organizations over the next 30 years.

In 1966 WHITETHROAT, which had been showing some deficiencies in seaworthiness which limited her usefulness as an operational research vessel, was replaced as the junior research ship by CNAV LAYMORE. She was built in 1944 as a USN supply vessel, then purchased by the RCN and arrived in Esquimalt in 1946 as CNAV LAYMORE. For many years this vessel served as a carrier between Esquimalt and Lynn Creek bulk stores in North Vancouver. She also served as a freight carrier and supply vessel to many agencies over the years. She participated in Fraser River flood relief in 1948, and carried army supplies to the Yukon via Skagway in 1950. Particularly notable were her monthly trips to Monterey California for silica sand for the dockyard sandblasting, and her role as a minelayer and



LAYMORE

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[22] When the ship was first fitted out she was considered to be too light and a lot of ballast was added, changing the roll period from that calculated in the design. The engineering firm which had designed the flume tanks specified modifications which changed the resonance period by more than a second and the problem disappeared.

recovery vessel for exercises with the 2nd Minesweeping Squadron. With the closing of the Lynn Creek stores at about the same time that WHITETHROAT was ready for retirement, LAYMORE was converted to a general purpose oceanographic research vessel. Many changes were made to carry out this new role, such as extra accommodation for scientists, a new laboratory, anti-roll tanks for stability, a much larger wardroom, a modern galley, increased electrical power and a very modern and handy wheelhouse with most of the modern electronic aids. She retired from service in 1976, and was not replaced; by that time Fisheries and Oceans had begun to assemble their own fleet of vessels, thereby eliminating the need for two DND research ships on the West Coast.

Investigations were undertaken to obtain a better understanding of the environmental phenomena which affect submarine detection using underwater acoustics in both the Pacific and Arctic. In the Pacific, the emphasis was on long-range sound propagation and reverberation (backscattering of sound from inhomogeneities in the ocean volume and its boundaries). In the Arctic, there was such a dearth of knowledge that all the parameters such as propagation loss, ambient noise, and under-ice reverberation were investigated.

Ocean Acoustics

A number of experiments were carried out in co-operation with US laboratories to investigate long range sound propagation in the Pacific.[23] In July 1960, scientists from PNL and USNEL conducted studies of the fluctuations of convergence zone and bottom reflected signals in areas 500 miles west of Vancouver Island and in the Aleutian Trench region of the Gulf of Alaska. There were two more experiments the following year, one off San Clemente Island, and the other, conducted in co-operation with Scripps in the waters to the west of Dixon Entrance and the Queen Charlotte Islands. Two further experiments were conducted in 1965 to measure seismic arrivals. Following this the work on long-range sound propagation was placed in abeyance. The emphasis now shifted back to active sonar, in response to a request from the Air Force for assistance in explosive echo-ranging (EER).

In the late 1950s, western airforces, including Canada's, became interested in explosive echo-ranging. In this application, the sound source is a small charge—approximately equivalent to 0.8 kg TNT—dropped from an aircraft. The echo from the submarine target is picked up on a sonobuoy also deployed from the aircraft. EER trials were conducted by the laboratories on both coasts, those involving the active participation of PNL staff being carried out in 1960. In one of these, Joe Scrimger and John Tully flew in a patrol aircraft to test one of the latter's latest brainchilds, employing echoes from the bubble clouds generated by a line of submarine decoys to determine the 'range of the day.' This marked the end of the direct participation of PNL staff and Dr Tully in joint field trials; for over a quarter of a century, Dr Tully, though not employed to do defence research, was certainly among its most ardent and articulate supporters and participants.

Because of the wide-band nature of explosive sound sources, it is not possible to exploit the doppler associated with moving targets, thus rendering EER systems highly susceptible to interference from the reverberation background. Accordingly, a knowledge of the characteristics of this backscattered sound is essential for optimizing system design and performance. Therefore PNL initiated studies to investigate the reverberation background at the low frequencies applicable to explosive echo-ranging sonar. The basic research tool was the effectively co-located small-charge/omnidirectional-hydrophone combination used in echo-ranging. Because of its simplicity, wide-band characteristics, and the surprising amount of information that it could elicit on the scattering properties of the ocean and its boundaries, the results obtained were widely applicable in active sonar and not restricted to EER. Over the next decade, this experimental arrangement proved to be an effective research tool in PNL's studies, not only in the Pacific but in the Arctic as well.

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[23] The sound sources of choice for these investigations were underwater explosives—convenient, energetic and wide-band. The last is particularly important as it greatly facilitates the investigation of the frequency dependence of underwater acoustic phenomena. Charge weights normally ranged from about one half to one kilogram of TNT, but on occasion either much smaller or larger charges were employed.

In the fall of 1961, Joe Scrimger received a two-year posting to the Hudson Laboratory, in Dobbs Ferry, NY, to work on low-frequency reverberation for the Artemis Project. Artemis was a massive research project designed to demonstrate the limits in active sonar surveillance achievable with current technology. After the posting, he continued his association with the project, returning to the Artemis installation in Bermuda in both 1963 and 1964 to conduct measurements of backscattering from the ocean surface and bottom. Meanwhile at PNL, Ray Brown initiated a program to investigate sound scattering from the sea surface and its dependence on sea state, a program which continued through 1966 when the emphasis changed to acoustic surveying of the volume reverberation in the Northeast Pacific.

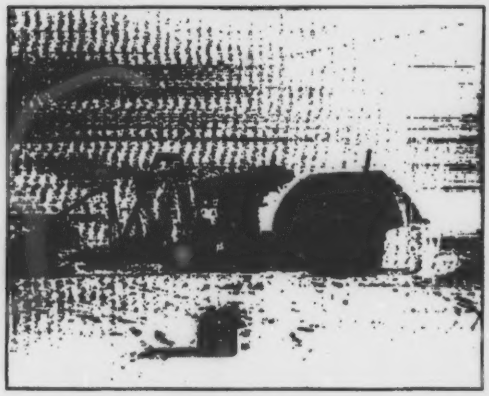
Arctic Acoustics

Underwater acoustic research in the Arctic proved to be particularly rewarding. Because of its unique characteristics, essentially every set of measurements produced new, often quite unexpected results, much to the benefit of the PNL scientists led by Al Milne. Success was made possible through the generous co-operation of several Canadian agencies, including the RCAF, the Department of Mines and Technical Services, and the Department of Transport .

In the earlier trial, carried out under the relatively uniform shore-fast ice of Barrow Strait, the noise levels were surprisingly low and the sound propagation was very good. In 1961, two operations were conducted to extend the measurements to different types of ice cover. The first was carried out in the spring under rough polar pack ice in the Prince Gustaf Adolph Sea. Noise levels in March were extremely variable, with night-time values being as much as 30 dB higher than those measured at mid-day, an effect attributed to ice-cracking caused by the decreasing, low temperatures at night. With the higher temperatures in April, this effect had largely disappeared. Due to the rough ice, sound propagation was much poorer than that which had been measured under the shore-fast ice. The second experiment was carried out in the late summer in M'Clure Strait under a virtually continuous ice cover of mixed polar pack and quasi-annual ice. Sound propagation was considerably better than that in Prince Gustaf Adolph Sea and the ambient noise showed little variation with time of day. This completed the initial survey to obtain quantitative data in a region where none existed before, and to determine the level of effort required for a realistic assessment of the potential for submarine detection in the Arctic.

Stimulated by the under-ice transit of the NAUTILUS, US scientists were also becoming increasingly interested in the Arctic and in co-operating with PNL. Initially, and for the next decade, such co-operation was ad hoc and sporadic, but later grew to became a consistent and important feature of the Laboratory's Arctic research program. An experiment was carried out in April 1962 in co-operation with the USN Underwater Sound Laboratory (USNUSL) to measure long-range sound propagation in the Arctic Basin. USNUSL manned stations on two ice islands, Arlis II and T3, and fired the shots used as the sound sources. PNL staff, assisted by a scientist from POG, established two receiving stations on the ice approximately 150 miles northwest of Mould Bay. In addition to receiving the sound from the ice islands, PNL also conducted reverberation measurements, and short-range propagation runs using shots deployed from a DM&TS helicopter. As the personnel and equipment were flown up to Isachsen by the RCAF, and the camps established using Otter aircraft owned by DM&TS, this well illustrates the level of co-operation required to conduct experiments in the Arctic.

Site of April'62 Can/US experiment



April'62 icecamp supported by RCAF DC-3

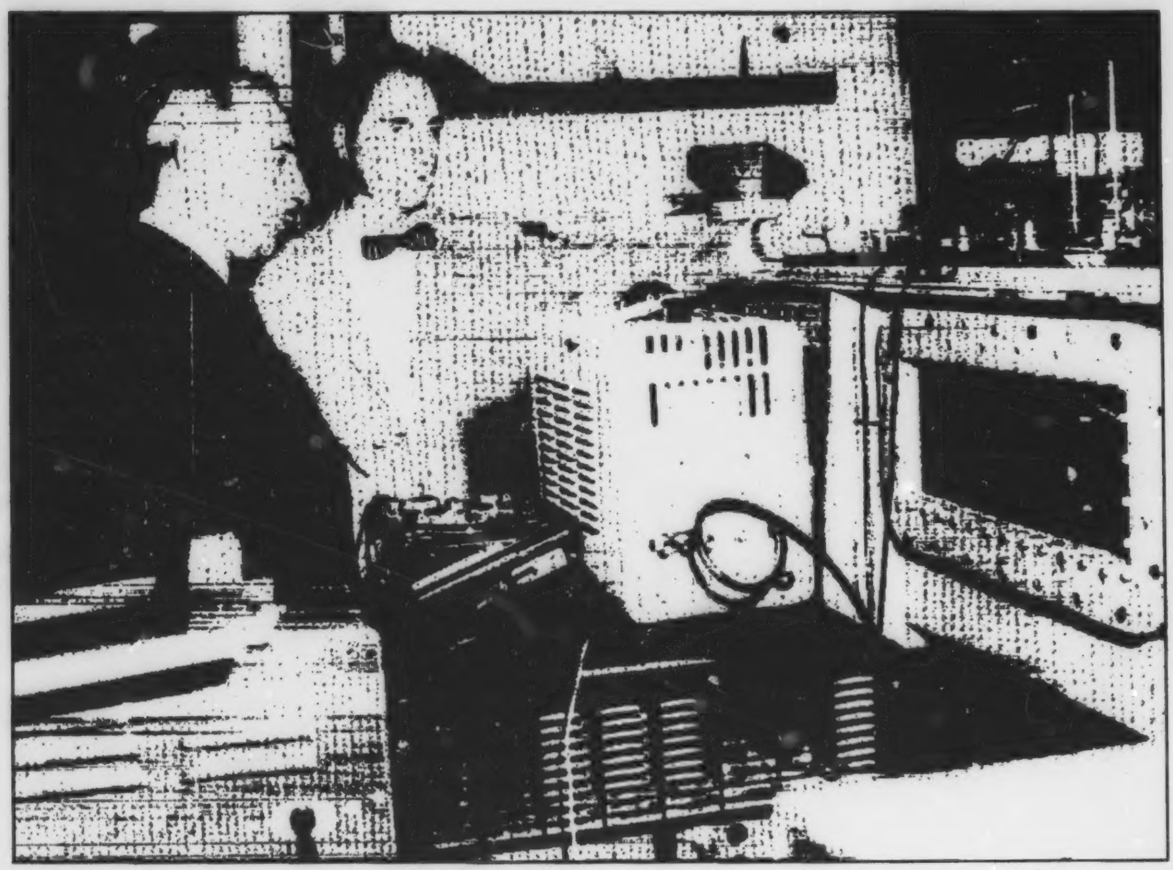
Two field operations were carried out in 1963. One, a follow-on to the earlier experiment where thermal stresses due to ice warming and cooling caused large diurnal excursions in the background noise, was designed to repeat the operation in the depth of the Arctic winter when no solar radiation is present. Under these conditions, the predominant noise generating mechanism appeared to be associated with the drifting of granular snow over the sea-ice. However, the expectation that noise from thermal stresses would not occur in the absence of diurnal heating was quickly disabused. During periods of decreasing air temperature associated with the movement of large air masses, high levels of impulsive noise occurred with peak pressures up to 40 dB above the background. Additional measurements made on four field trials during the next three years demonstrated the complexity of the ambient noise problem and pointed to the necessity of making long-term measurements at selected locations. In response, the Recording Instrument Package (RIP) was developed. The RIP was a self contained package which could be placed on the sea floor during open water conditions in summer and which could be retrieved the following year. It included a single omni-directional hydrophone connected to a digital tape recorder. Once each hour for more than a year the noise pressure could be sampled in six frequency bands an octave apart. By this means, estimates of the spectrum of the noise pressure and its annual variability could be obtained. By late 1966, five of these instrument packages were under construction for installation in the Arctic Archipelago the following summer.

In September 1963, Ray Brown conducted a backscattering experiment from a camp set up on an ice floe in the shallow waters of Prince Regent Inlet. Although the ice was fairly smooth, backscattering was relatively high—similar to that experienced in open seas driven by 30 knot winds. During three field trials carried out over the next two years, measurements were extended to rougher, more-intense-scattering ice surfaces. The results of these experiments were published in the open literature and remain the definitive references on this subject.

Fluid Dynamics

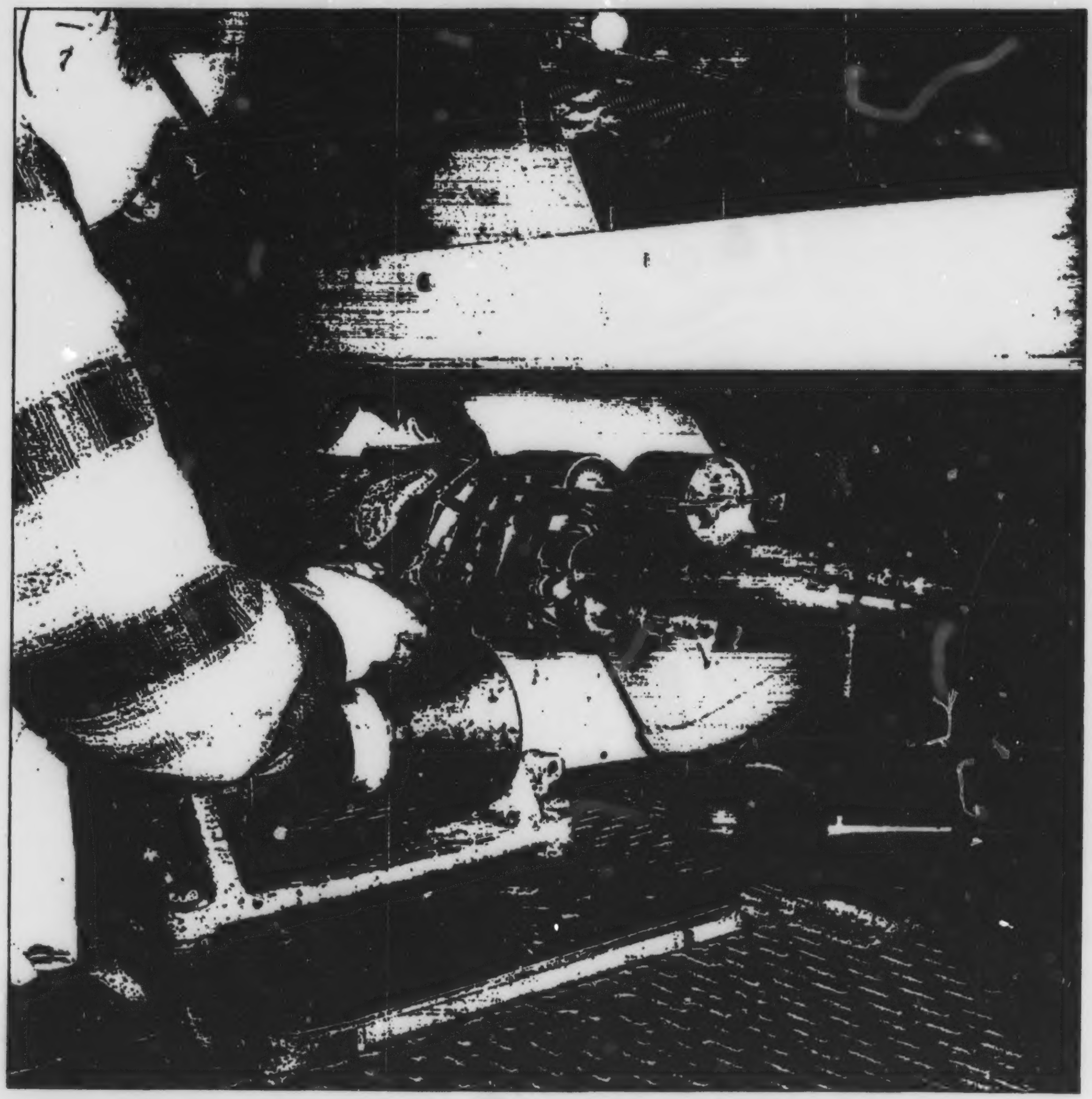
In 1960 the turbulent wakes of two surface ships operating in calm seas were detected using heated-film probes. Sufficient confidence having by then been developed in the measuring equipment, plans were made for a submarine-mounted version. In both of the next two years—thanks to the generous support of the Flag Officer Pacific Fleet—PNL scientists were able to install appropriate instrumentation in the submarine HMCS GRILSE and to carry out trials in oceanic waters. These operations proved to be very successful in that observations of the turbulent wake of the submarine were obtained which indicated that submarine wakes were persistent and could be observed by combined velocity-temperature sensors.

Instrumentation was then developed which permitted the measurement of the naturally occurring temperature and velocity microstructure down to depths of 1,200 feet. To achieve this



Ashton Patterson displaying the low-turbulence water tunnel to the Minister of National Defence, Douglas Harkness

depth, the sensors were mounted on a heavy, streamlined instrument platform towed from CNAV ENDEAVOUR. Obtaining the level of platform stability required for the hot-film flowmeter required sophisticated depth control equipment and a considerable effort went into its development. While this was going on, the research staff busied themselves with studies of the surface effects resulting from wake collapse as a ship or submarine moves through water having a strong density gradient. Experiments in Georgia Strait with surface ship wakes were carried out in the summer of 1965 which, along with associated theoretical studies, threw considerable light on the complex relationship of visible surface effects to the internal waves produced by collapsing wakes.



Microstructure measuring probes being withdrawn from torpedo tube of HMCS GRILSE

Electromagnetics

The electromagnetics research program continued its investigation of the factors affecting the detection of submarines by low-frequency electromagnetic means. In order to obtain results of general applicability, consideration was given to the various factors affecting the generation and propagation of the naturally-occurring radiation, including that of the ionosphere, thunderstorms and local geological structure and the effect of solar disturbances such as solar winds, magnetic storms and auroral displays. This involved the extension of the scope of the experiments, including the geographic coverage. A growing interest in the program by outside organizations resulted in the participation of the Universities of British Columbia, Alberta and Texas in experiments carried out in 1960 to determine the distribution, coherence and amplitude of the naturally-occurring radiation at Ralston, Albert Head and the Dominion Observatory in Ottawa.

For some time the PNL scientists had been planning to extend operations into the Arctic as it was thought that polar auroras were somehow connected with some of the low-frequency electromagnetic noise which they had been observing. A fortuitous visit by a scientist from Stanford University in early 1960 resulted in the formation of a joint Arctic-Antarctic experiment to study the noise background at two stations, one at Byrd Station in the Antarctic and the other near its magnetic conjugate point,[24] at the mid-Canada line radar site at Great Whale River in northern Quebec. In addition, PNL was also to operate a station at Fort Churchill, where auroral measurements were available. Using this location, results could be compared across Hudson Bay as well as between the Arctic and Antarctic conjugate points. The conjugate points were particularly interesting because a propagation path along the earth's magnetic lines of force was known to exist at lower latitudes; if the auroral zones were closely related to the sources of the noise, then the activity at the conjugate points in the auroral zones should be closely connected. The experiments were designed to have PNL cover the lower frequencies—0.01 Hz to 30 Hz—and Stanford the higher—10 Hz to 15 kHz. Thus equipment was sent by PNL to Byrd station, and by Stanford to Great Whale River.

Don Evans (2nd from left) and Sir Charles in Antarctica (National Science Foundation Photograph)

The PNL equipment at Great Whale River was manned by Art Shand and Chris Gibb, and that at Fort Churchill by Erwin Lokken and Ray Hale. The Stanford equipment at Great Whale River was operated by Lin Martin, a New Zealander with considerable Antarctic experience, having been in charge of New Zealand's Scott Base for eighteen

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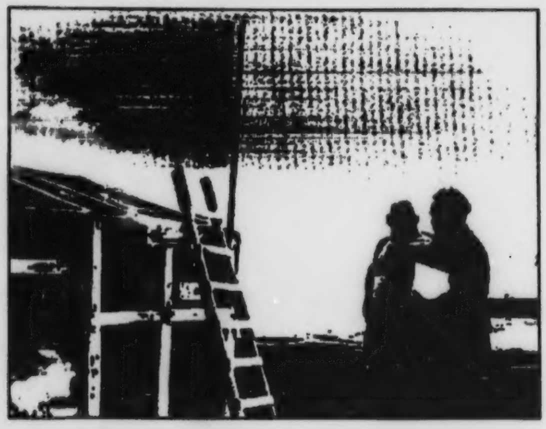
[24] The point at the northern end of the magnetic line of force which starts at Byrd Station in Antarctica.

Wright Valley (NSF photograph)

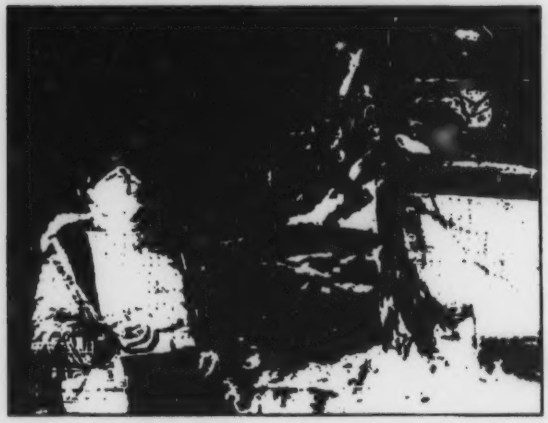
months during the International Geophysical Year. Sir Charles Wright and Don Evans were loaned to Stanford to operate the PNL equipment at Byrd Station. While there, Sir Charles managed to see a number of the signs of the Scott expedition, including the hut in which the party spent the winters of 1911 and 1912 and a geographical feature which had been named Wright Valley in his honour. The unchanged rugged ice-covered terrain recalled to Sir Charles a vivid picture of the hardships and achievements of the era of early Antarctic exploration. The icebreakers, airstrips, helicopters, tractors and air-conditioned quarters were a sharp reminder of how much times had changed.

Experiments carried out in January 1961 were outstandingly successful. Large impulsive events at frequencies below 1 Hz, lasting from 2 to 15 minutes, and associated with unusual auroral displays were observed to occur simultaneously at Great Whale River and Byrd Station.



Sir Charles Wright and Leslie Quartermain outside the magnetic shack used by George C. Simpson during Scott's expedition. Main Scott hut can be seen in the background. (NSF photo)

Sir Charles in darkroom of Scott's hut at Cape Evans. This darkroom was used by the famous Antarctic photographer Herbert Ponting during the Scott 1911-1913 expedition. (NSF photo)



Sir Charles looks at bunk he used as a young physicist with Scott's expedition. Bottom bunk was used by another young scientist, George C. Simpson. (NSF photo)

Sir Charles signs guest log in Shackleton's (1908-1909) hut. The log is maintained by New Zealand which is restoring the historic site. (NSF photo)

Continuous signals, lasting for hours and showing a preference for narrow frequency bands, were also observed. As their envelopes were highly correlated over great distances—Byrd Station, Great Whale River and Victoria—and as the signals showed a pronounced band structure at 8, 14 and 20 Hz, the Schumann resonance modes of the earth-ionosphere cavity, the most likely source of this disturbance was considered to be world-wide lightning.[25] In December, a second conjugate point experiment was carried out between Quebec City and a new station in the Ellesworth Highlands of Antarctica. Initially it was feared that the excursions into polar latitudes might well complicate the picture. Happily, the classification of types and probable sources of electromagnetic disturbances and their modes of propagation were greatly clarified by the conjugate point work.

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[25] This inspired the launch of a new co-operative program, with the National Bureau of Standards at Boulder Colorado, to study the propagation of disturbances from lightning along a line—Florida-Boulder-Victoria—approximately normal to the earth's magnetic field lines.

These investigations of the correlation of the properties of electromagnetic fields over long distances continued for several years, expedited through contracts with Sir Charles Wright and two assistants at PNL, and Professors J.A. Jacobs at UBC and L.P. Geldart at McGill. PNL continued to update the measurement equipment at Byrd Station, Great Whale River, St Hilaire (PQ), Ralston and Westham Island. The stations at St Hilaire and Westham Island were operated under contract with McGill and UBC respectively. The other three were operated jointly by DRB and Stanford. In 1964, the Great Whale Station was transferred to NRC, and Professor Jacobs' contract was extended to cover the analysis and interpretation work being carried out by Sir Charles.

In 1961, a separate project on Magnetic Anomaly Detection (MAD) was set up to concentrate on the natural fluctuations of the earth's field in the frequency band 0.001-1 Hz and to investigate possible techniques for minimizing the effect of these micropulsations on MAD system performance. The project was planned in consultation with the Magnetics Group of the National Aeronautical Establishment (NAE) in Ottawa with the objective of specifying the natural limitations placed on air-borne magnetometry by both the geomagnetic (time-varying) and geological (structure) noise. Early in the program, PNL's responsibility was to provide surface monitoring—on land and sea—while NAE was making the airborne observations. Later, as the program matured, PNL scientists would become much more actively involved in the airborne measurements. This program was influenced to considerable extent by the advent of new magnetometers of greatly increased sensitivity which introduced the possibility of effecting marked improvements in the detection capabilities of current MAD systems. The then recent development of the optically pumped electron precession magnetometer meant that the over-all system noise was no longer limited by the magnetometer, thus justifying a considerable effort to reduce

Sir Charles, the last of the Scott expedition to reach the South Pole, photographed here with Mr Keith Sinclair, Editor, Melbourne Age and Sir Rowhan Delacombe, Governor of Victoria, Australia. (NSF photo)

noise from other sources.

The first measurements were carried out in 1962, when NAE, in co-operation with DM&TS, undertook an airborne survey of an area off the Scotian Shelf to determine the characteristics of geological noise produced by aircraft motion relative to anomalies of geological origin. An optically pumped electron precession magnetometer was used in an RCAF Argus aircraft for the survey. PNL provided equipment for simultaneously monitoring time-varying noise at shore-based stations on Sable Island and at Hartlen Point near Halifax. Later in the year, fluctuation measurements were also carried out in the Pacific, in co-operation with the University of California and the US Navy base in San Diego, using the first prototype of a magnetic buoy then being developed at PNL.

An extensive investigation of fluctuations in the low-frequency electromagnetic background was carried out in co-operation with NAE in April and May 1965 in the vicinity of the Bahamas. Logistic and operational support was provided by the Canadian icebreaker, C. D. HOWE. Airborne measurements were made by NAE personnel operating from an RCAF North Star aircraft—then on loan to NAE but flown and maintained by the RCAF. The experiment, designed to intercompare measurements of the micropulsations made simultaneously from a land station, from an aircraft and with sensors suspended in the ocean from floating buoys, produced interesting and useful results. An encouraging degree of similarity was experienced between the signals measured in the three environments, high correlations being experienced for separations up to 90 miles between the land station and the magnetometer buoy, and 180 miles between the land station and the aircraft. These results were at variance with those obtained two years earlier in the Arctic using a string of magnetometers sitting on the ice of Barrow Strait near Resolute. There, marked phase changes were observed to occur between micropulsation signals received at stations spaced only 2 to 4 miles apart in the centre of the ten mile wide channel. Moreover, at the University of Victoria, Professor H.W. Dosso had just shown, with the use of a physical analogue model and simulated micropulsation signals, that appreciable phase and amplitude changes to the several electric and magnetic components of the signal could occur near a coastline owing to the difference in electrical conductivity of sea-water and land. In addition, if large masses of rock with much higher than average conductivity were present, the pattern of phase and amplitude changes would be even more complicated. Thus the high coherence found between the sea and land measurements in the Bahamas could well have been a special case. The area had, in fact, been chosen deliberately because it was free of anomalies, and it was also possible that the porous sand and coral beneath the site of the ground station was so well penetrated by sea-water that there was little change in conductivity between it and the sea.

It therefore appeared likely that similar experiments on the BC coast, where much of the underlying rock produces strong magnetic anomalies, would show that a much more complicated relationship existed between the components of micropulsations received on land and on sea; phase changes over short distances, such as those found in the Arctic channel, might be expected. Accordingly, experiments were carried out in May and August 1966 with lines of magnetometer buoys placed across a seawater channel off the east coast of Vancouver Island and in the open sea off its west coast. As expected, the results from these operations showed that considerable phase changes did occur between micropulsations received by land stations and those received at some of the buoy positions. This series of experiments also confirmed an earlier observation that the buoy magnetometers detect, in addition to the micropulsations, magnetic signals produced by the electrical eddy currents in long-period ocean swell. A theoretical explanation for this effect was developed by Dr J.T. (John)Weaver—then on the PNL staff, but later Head of the Physics Department and Dean of Science at UVic.

Electromagnetic detection systems are inherently short range, thus restricted in the deep ocean to applications such as MAD where an aircraft flies directly over the target. In shallow water harbour approaches and channels, bottom-mounted systems are also feasible and the development of techniques to improve their performance had been a consistent feature of the PNL program since its inception. The then most recent development, which provided impressive improvements in the signal level relative to that of the noise, was a scheme to cancel the noise background at a particular sensor based on its relationship to that of a nearby reference sensor.[26] By permitting a much more detailed examination of the characteristics of the electromagnetic signals emitted by marine vessels than had previously been possible, it led to an expansion of the program to include the signals radiated by both surface ships and submarines.[27] The initial measurements in this activity were carried out in 1966 at Dabob Bay, Washington, in co-operation with the US Navy.

Materials Technology

Ralph Barer conducts the Associate Minister of National Defence, Lucien Cardin, on a tour of Materials Technology

Materials research continued in a number of areas of metallurgy, chemistry, anti-corrosion and paint.

The effort in metallurgy concentrated on studies of ultrasonic transmission through metals and relating metallurgical variables to the first stages of fatigue. The development began of methods for the *in-situ* determination of wall thickness of boiler and superheater tubes of RCN ships. A Thulium 170 nuclear gauge was developed for the determination of the wall thickness of superheater tubes. This invention, and its implications for replacing the "wear and waste" method of determining the life of superheater tubes—a process used by the Royal Navy for a hundred years—received considerable recognition and discussion at the Second Inter-Naval Corrosion Conference in 1965. For several years—until the conversion from steam to turbines—the adoption of this technique resulted in very substantial savings to the RCN in money and downtime. Incidentally, the obvious attractiveness of this approach quickly caused the RN to follow suit.

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[26] Due to the significant changes in the characteristics of the noise background over short distances, this was far from a straight-forward subtraction. Stimulated by the measurements made in the Arctic in 1963, a method—based on a phenomenological theory relating vector quantities measured at one location to similar quantities at another location by way of a time-independent tensor function of frequency and of the dual positions—was developed to address the problem.

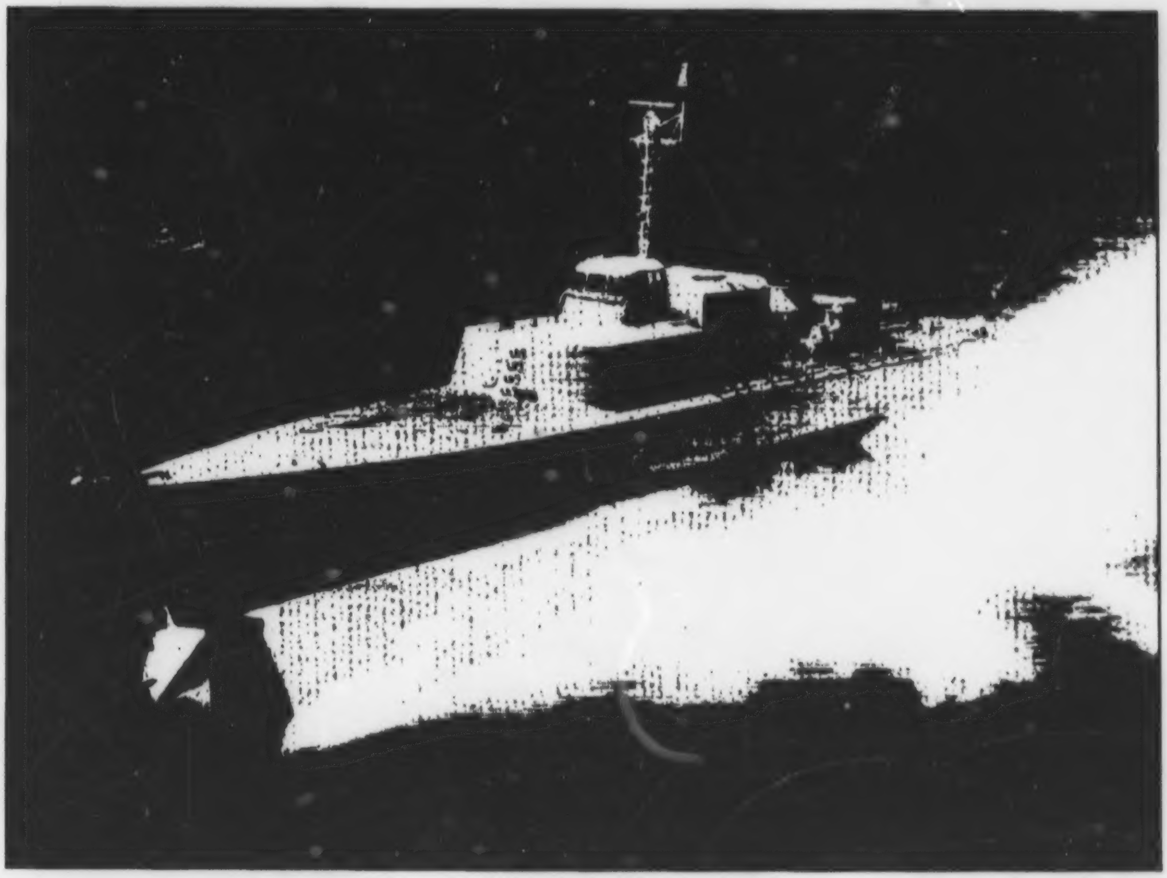
[27] As the same signals are also used to detonate mines, the expertise developed in this program was directly applicable to the ship-quietening aspects of mine countermeasures.

In chemistry, research focussed on methods aimed at extending the speed, accuracy and versatility of the Laboratory's spectrographic facilities. Flame spectrophotometry proved to be particularly useful for the rapid analysis of certain metals. Methods were developed for determining copper in major and minor amounts in a number of engineering alloys widely used in naval applications. Flame analysis also proved useful in detecting metallic contaminants in lubricating oils. The method was first applied to the machinery on two destroyers and the submarine HMCS GRILSE. Such testing later became standard for all navy ships stationed on the West Coast.

At this time, the superheaters of all the destroyers on the West Coast were faced with major overhauls because vanadium oxide, present in South American bunker oils, had gummed them up. Dick Sewell, based on his wide general knowledge of chemistry, quickly developed a method for cleaning them, an action which resulted in very considerable savings to the Navy.

The research on combating corrosion of ships hulls had for some time been concentrated on zinc anode systems. By 1960, OSHAWA, a large tug, an RCMP patrol craft, and a number of small tugs and harbour craft had been fully protected by high purity zinc anodes for up to 5 years. These installations having demonstrated the reliability, self-regulating features, and economic advantages of zinc anode systems, the Navy then proceeded to fit them on their frigates and destroyers.

The maraging steel of the Navy's experimental prototype hydrofoil, the FHE-400,



FHE-400

experienced severe cracking. Research was initiated in 1964 to investigate the behaviour of stressed maraging steel in seawater, including the evaluation of its corrosion fatigue behaviour and the evaluation of the stress corrosion behaviour of welded specimens of the actual foil material.

The research continued on the adhesion of paint to ships' hulls and the tendency of paints containing metals to deteriorate when subjected to cathodic protection currents. As a result of these studies it was recommended to the Navy that vinyl-aluminum become the standard underwater hull paint system. It was used successfully on two test platforms, HMCS SKEENA and HMCS ANTIGONISH.

Tony Moilliet modelling Dick Sewell's emergency floatation device

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In July 1966, Dr Sanders retired as Chief Superintendent and was replaced by Mr R.F. (Bob) Chinnick. Both Dr Sanders' times at PNL featured substantial growth in programs and personnel with the attendant outgrowing of facilities. Both times before he left, he initiated building programs which, at least temporarily, relieved the congestion. Fred's view on the subject was expressed poignantly in a memorandum he wrote early in the year following his retirement.[28]

> The activities and staff of PNL have grown at a faster pace than was anticipated when the laboratory was built, and the present staff of over one hundred has been somewhat hampered for lack of working space, This situation will be remedied when a new wing, of approximately ten thousand square feet, will be opened in May of this year. While the continuing expansion is an indication of healthy growth and recognition of valuable research being carried on and planned for the future, some look back with nostalgia on the small beginnings in the wooden buildings on Black Rock.

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[28] Ibid. F.H. Sanders (footnote 2).

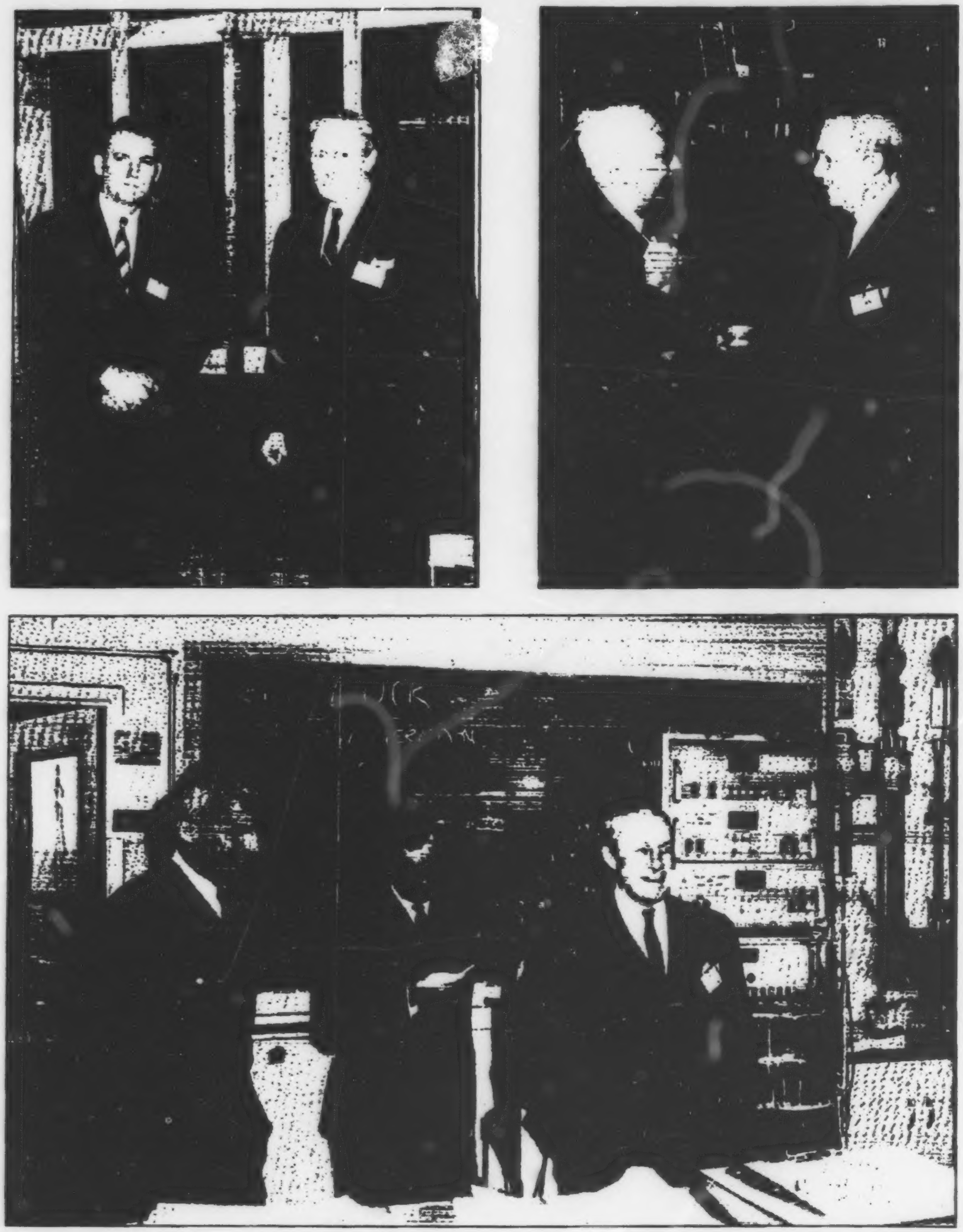
1967 to 1969 - PNL becomes DREP - a north wing added to Building 199

Organization, facilities and trends

In 1967, the name of the laboratory was changed to the Defence Research Establishment Pacific (DREP). This was primarily an administrative change designed to achieve uniformity of nomenclature among the various DRB establishments and as such had little observable impact on either the Laboratory or its programs.

Mr R.F. Chinnick joined DRB in 1950 and served at the Canadian Armament Research and Development Establishment (CARDE) in a number of capacities until 1964. He then attended the National Defence College in Kingston, following which, he was appointed Director of Physical Research at DRB/HQ. A year later he became the Superintendent at DREP where, during the next three years, he oversaw a number of significant changes in facilities, external relations and program. The North Wing was officially opened. Increased responsibility was assumed in direct liaison with the Canadian Forces, in the DRB University Grants program, and in The Technical Cooperation Program (TTCP).

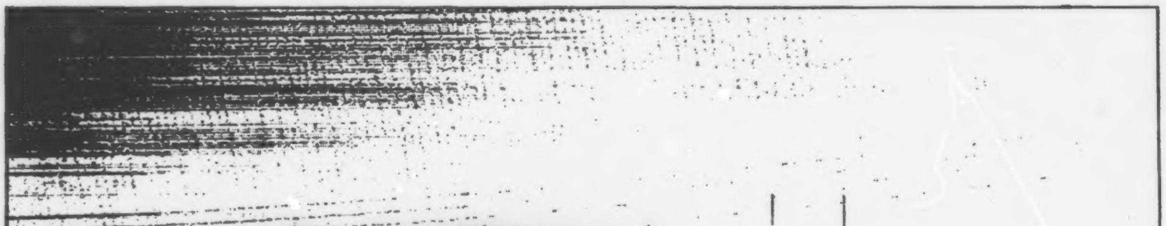
Despite its unfortunate position relative to the 8 ball—an artificial submarine target—the Laboratory's future looked bright



Dr Zimmerman's farewell visit: (top left) viewing North Wing construction with Mr Chinnick; (top right) chatting with Sir Charles; (bottom) touring Electromagnetics with G/C Maclure.

A number of system studies were conducted in an effort to improve the match between the DREP research program and CF system development and operational requirements; in 1968 and 1969, a study was carried out to specify the optimum torpedo countermeasures suite for the DDH-280; in 1969, DREP and NAE examined—on behalf of the DRB Advisory Committee on MAD—the whole of the magnetic anomaly research and development activities being carried out in Canada; and in late 1969, a study began on the current status and future possibilities to be expected from the internal-wave investigations. Planning was also initiated for a substantially increased effort in the Arctic, in support of surveillance in the channels. The major part of the increase was to be at the expense of the environmental studies in the Pacific. There was also some reduction in fluid dynamics, where plans were being made to transfer the work on small scale temperature and velocity structure to another department whose mandate more clearly encompassed leading edge oceanography.

The research vessels CNAV ENDEAVOUR and CNAV LAYMORE continued their very high usage at sea. They, along with the Department of Energy Mines and Resources' (DEMR) vessels CSS PARIZEAU and CSS VECTOR were, by 1968, scheduled as a West Coast Ship Pool to serve a much larger client base, which now included DREP, DEMR, POG, UBC, UVic, and the Marine Services and the Observatories Branches; activities encompassed such disciplines as deep ocean acoustics, turbulence, gravity, geology, seismology, and physical, chemical, and biological oceanography. This arrangement resulted in maximum usage for all the vessels and provided the best efficiency in matching the vessels to the jobs.



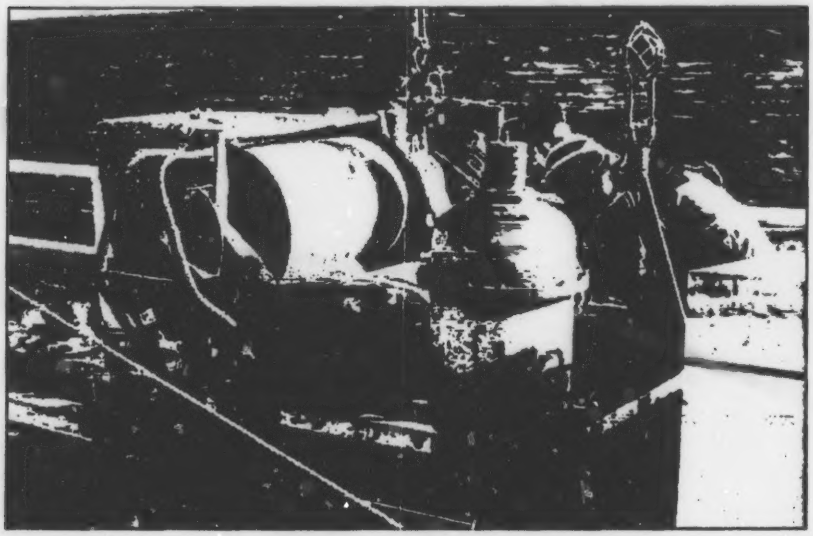
North Wing extension housing Electromagnetics, conference rooms and receiving stores

Ocean Acoustics

The scattering of sound in the volume of the open ocean is dominated by biological organisms which congregate in layers, many of which experience pronounced diurnal migrations in depth. As a number of the organisms use gas-filled swim bladders to control their buoyancy, they are highly resonant, thus enhancing their backscattering strengths and making them highly dependent on frequency, depth and time of day. The types and distributions of these marine organisms and their combined backscattering were known to vary considerably from ocean to ocean, and to a lesser extent, geographically in the same ocean basin. As this sound scattering impacts strongly on sonar performance, a program was initiated to investigate the acoustic characteristics of volume scattering in the Northeast Pacific. Measurements were made initially at a small number of sites to develop data collection and analysis techniques suitable for large scale surveying.[29]

A program to investigate the seasonal dependence of low-frequency ambient noise in the Northwest Pacific was also initiated. In 1969, refurbished RIP units—their utility having been clearly demonstrated in the Arctic channels—were placed on the summits of three seamounts, Bowie (37m), Union (305m) and Cobb (35m), to measure ambient noise over a one year cycle.

Arctic Acoustics



Preparing a RIP for deployment

In the summer of 1967, an experiment was initiated to provide long-term samples of under-ice ambient noise. During a five-week cruise of the icebreaker CCGS LABRADOR, five RIPs were installed on the sea bottom at sites in the Canadian Arctic Archipelago: Lancaster Sound; Barrow Strait; Viscount Melville Sound; Norwegian Bay; and Baffin Bay. A year later, all but one were recovered by means of the acoustic interrogation system incorporated in the units. The one which couldn't be located was at the site in Baffin Bay, then occupied by a massive iceberg grounded on the bottom. Samples of ambient noise were obtained for various durations, with the longest being eight months. The results showed that the character of ambient noise was vastly different in the fall, winter and spring seasons. The noise levels were lowest early in the year under solid ice, and their diurnal nature showed up very prominently in April. A notable feature of this expedition was the inclusion of the 2-man deep-sea submersible, *Pisces 1*, to assist in the recovery of the

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[29] The survey was the joint responsibility of Joe Scrimger—following his return from a one-year posting to DREV—and Dr R.G. (Glenn) Turner who had transferred to DREP from DRB/HQ in 1961.

RIPs, to make under-ice acoustic backscattering measurements, to explore geological structures, to obtain bottom samples, to observe and photograph biological organisms, and to make oceanographic measurements. Fifteen dives were made throughout the Archipelago, four of these in waters covered by sea ice, where in each case *Pisces* was launched through a small but stable polynya. The operation excited considerable interest outside DND, eliciting financial support from BIO, the Fisheries Research Board of Canada and the US Office of Naval Research.

Under shore-fast sea-ice, all the boundaries within which sound propagates appear to be relatively motionless. Since a high degree of stability exists—within a small fraction of a wavelength over the whole sound path—it should be feasible to cancel the interfering reverberation and hence improve the detectability of underwater targets. This idea was supported by experiments on sound propagation and reverberation carried out in 1968 and 1969, at ranges up to 30 miles, which demonstrated considerable phase stability in time and range.

Fluid Dynamics

Harold Grant adjusting sensor on the instrumented towed body used for measuring ocean microstructure

Two lines of investigation were continued on ways in which the ocean is modified by the passage of a submerged submarine: one was concerned with the detection of turbulent wakes against the background of natural turbulence in the ocean; the other was a study of the internal waves which are generated as the wake decays.

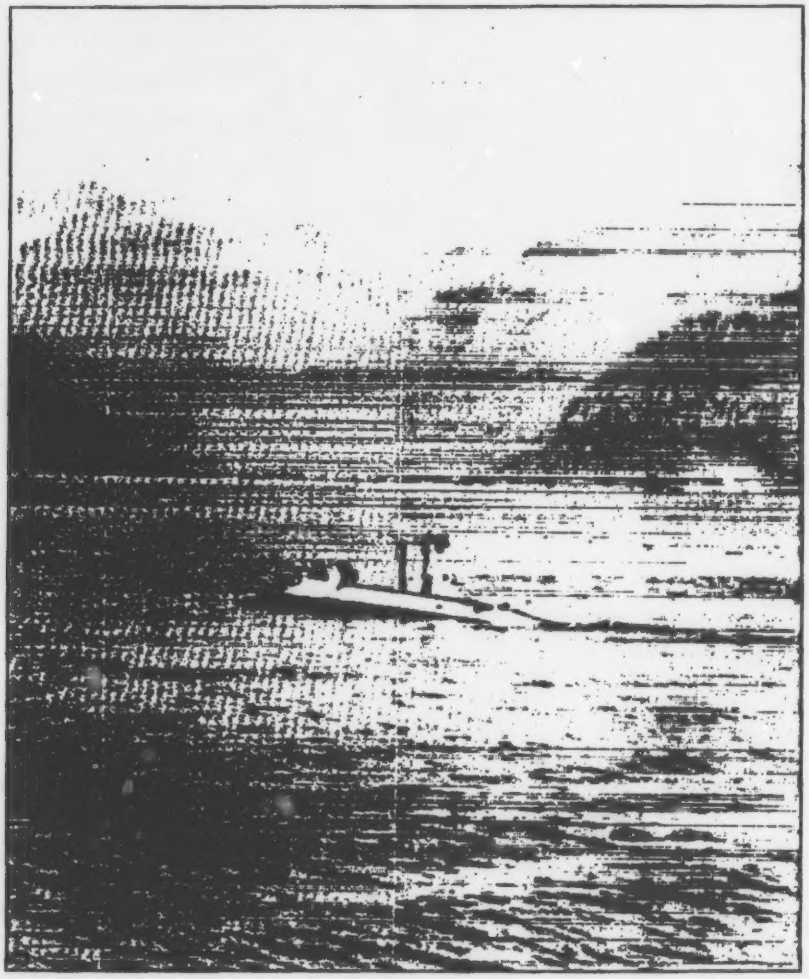
Measurements made at sea in June and November 1967, demonstrated that equipment noise for the deep towed system had now been reduced to the point where it became possible to measure velocity fluctuations in the open ocean. A successful cruise, using this equipment, conducted in January 1969, yielded much new information on the small scale structure below the main thermocline. Over this period the amount of in-house effort devoted to the project had been scaled back considerably. Most of the work was being conducted by Pat Nasmyth who, at the time, was working on his doctorate at UBC, with a thesis topic based on the analysis of the 1967 and 1969 trials data.

The production of a turbulent wake in water whose density varies with depth requires work against gravitational forces and that the wake contains potential energy, some of which is radiated away in internal gravity waves. These waves are attenuated very slowly, and they therefore offer possibilities for detection. The most feasible approach would be to observe the modifications which appear in surface wind waves in the presence of internal waves. Initially, the DREP observations were made in the Strait of Georgia, between Vancouver Island and the mainland. There are well-defined layers of water in this body of water, and the surface effects of internal waves are often clearly visible.

The available research ship time in 1967 was used for the development of the equipment required to make internal wave measurements below the sea surface. The main instrumentation consisted of an array of seven current meters and a "fast bathythermograph," the latter presenting a challenging problem both in its development and operation.

Internal waves can be generated by either the collapse of the turbulent wake of a vessel or by the passage of its hull through the water. Both mechanisms produce a V-shaped wave on both sides of the track of the vessel. In addition, if the speed of the hull is below the maximum speed of internal waves in the prevailing density gradient, there is also a stern wave consisting of transverse internal waves which can become extremely strong under appropriate conditions. Progress in 1968 included numerical results from theory developed by Blyth Hughes to explain these phenomena and the first quantitative observations of internal waves generated by ships in Georgia Strait and adjacent waters.

In June/July 1969, an extensive experiment was conducted in Bute Inlet with strong support from the US Navy and the Canadian Forces, and the collaboration of the US Naval Research Laboratory (NRL) and the US Naval Air Development Center (NADC). The USN provided the 50-ft submarine, USS X-1. DREP made the sub-surface measurements from ENDEAVOUR, and made aerial photo-graphs from a helicopter of



USS X-1

visible surface effects of the internal waves, while scientists from the two US laboratories also made remote measurements of the surface effects, from an aircraft and from a camera mounted on a hillside.

Electromagnetics

In electromagnetics, the bulk of the effort, whether in-house or contracted to universities, was devoted to MAD. The program was driven to a large extent by the availability of the optically pumped magnetometers, ten to a hundred times more sensitive than the conventional magnetometers then currently in use, and of high speed airborne data processing computers which presented the possibility of decreased response time and increased effective system sensitivity. The full exploitation of the improved sensitivity required compensation for all sources of extraneous noise above the signal threshold. Research relating to noise arising from the airborne platform and its motion was centred at the Flight Research Section of NAE, while research into time varying geomagnetic noise and ocean swell-induced noise was undertaken at DREP.

The studies at McGill and UBC continued, those at McGill examining the various components of the micropulsation spectra and their spatial coherence, while those at UBC concentrated on the development of automated recording and processing techniques. The work with Stanford and NRC at Great Whale River and Byrd Station continued, but at a reduced level. This arose because the data required for the DREP MAD program required equipment much more sensitive than that used in the earlier micropulsation studies. The new requirement was for less, but more reliable, data that could be analysed routinely and very nearly automatically. To cope with the situation, a new more capable system was developed and installed at DRES, becoming operational in June 1969. Early observations demonstrated that the performance of conventional MAD systems employing state-of-the-art magnetometers would be severely degraded by micropulsation activity. To alleviate this problem, DREP initiated an investigation of filtering and data processing procedures.

Earlier investigations had indicated that the single most important source in the natural background limiting MAD performance is ocean swell moving through the earth's magnetic field. An understanding of this phenomenon was obviously important for the development of more sensitive magnetic detection systems so, in 1967, it was given a high priority in the electromagnetics program. The measurement of swell noise above the sea is much more difficult than measurements made below. Airborne measurements can be made, but the effect of aircraft motion prevents a detailed comparison between the magnetic signal and the swell. The magnetic gradients typical of the West Coast are such that an extremely stable mounting is required for the magnetometer. Fortunately, the presence of the off-shore drilling rig SEDCO-135F presented an excellent opportunity to measure ocean swell in an area of operational interest and under near optimum conditions. From December 1967 to April 1969, wave measurements were made from the floating drilling rig, both to compile wave statistics and for comparison with magnetic measurements made from the rig and from the NAE North Star. The joint DREP/NAE experiments involving air, land and sea observations facilitated both the development of an acceptable theory of the magnetic field due to ocean swell and recommendations of optimum flying heights to minimize its effect in operational situations.

Since the early 1950s, Canada had undertaken a program of research and development relating to magnetic anomaly detection, the work contributing substantially to the development of improved MAD detection equipment for the CF and its allies. It had stimulated industry and helped it to maintain the development and production of first-rate MAD noise reduction equipment for sale in Canada and abroad. Other government agencies, notably DEMR (Geological Survey), had also benefitted from the investigations of geomagnetic phenomena carried out as part of the program. To help co-ordinate this effort and ensure that CF requirements were met, DRB/HQ, in consultation with the CF formed, in 1968, the DND Advisory Committee on MAD Research and Development, with representatives from NDHQ, DRB, NAE, the Department of Defence Production and the Department of Industry. DREP became the office of primary interest (OPI) in MAD and provided both the Committee chairman and secretary.

Because of DREP's expertise in time-varying geomagnetic and ocean swell-induced noise and NAE's in airborne platform and motion noise, they were requested by the Advisory Committee to carry out a comparative quantitative analysis of the various noise factors affecting current and future operational MAD. The study identified five main types of noise which could affect MAD and reduce its effective range on submerged submarines: instrument noise, installation and manoeuvre noise, geological noise, swell noise and geomagnetic micropulsations. These types of noise depend on one or a combination of the following factors: the design and maintenance state of the MAD equipment itself, the magnetic field of the aircraft and its components, the aircraft's motions, the geographical locality in which the aircraft is flying, the state of the sea surface and of the earth's ionosphere and the action of the solar wind. The conclusions reached regarding the nature, approximate magnitude, effect on detection range and method of handling the respective types of noise had a considerable impact on later research and development activities in both the government and industry.

For several years, the Laboratory had been making measurements of the electromagnetic background at Extremely Low Frequencies (ELF). This band, from approximately 1 to 40 Hz, includes those frequencies at the fundamental and first few harmonics of a submarine's rotating propeller where corrosion currents between it and the hull are capable of radiating detectable electromagnetic signals. A measurement program was initiated with the US Navy Ordnance Laboratory (NOL) to record signals from submarine targets at a test range in Dabob Bay, Washington. DREP became involved in a number of aspects of this problem, including: the development of a model to compute the dipole moment associated with the rotating propeller, and the development of techniques to cancel the background noise and hence extend detection ranges.

Materials Technology

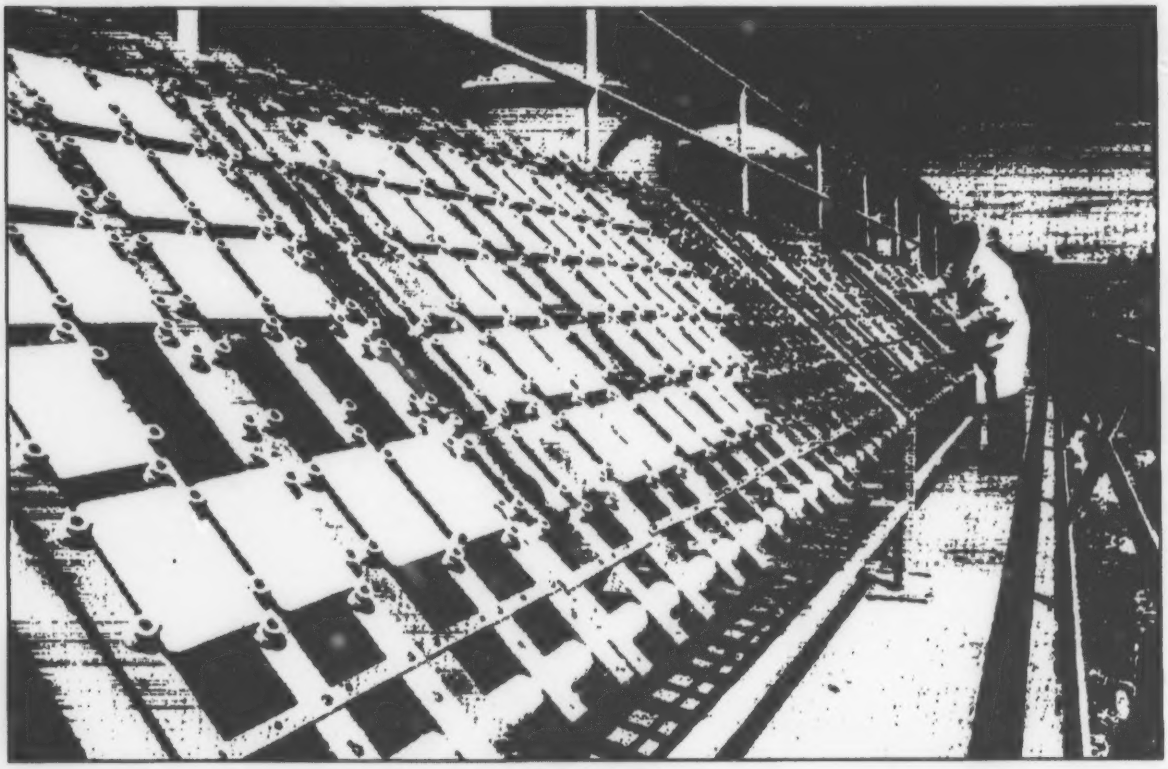
Research continued on stress corrosion cracking of maraging steel, nondestructive testing of marine boilers, propeller shaft grounding, inorganic analytical techniques and adhesion of paints. Part of the cracking problem of the struts on the FHE-400 was ascribed to welding stresses which resulted in severe hydrogen embrittlement when sea water leaked into the zinc coated interior of the main foil. A chemical method was devised to remove the zinc coating and work was started on the development of an inhibitor to prevent cracking if the strut flooded after the zinc had been removed.

An ultrasonic gauge, developed for evaluating super-heater boiler tubes *in situ*, was used successfully on warships on both coasts. Plans were made for improvements leading to more automated handling and readout. An electronic device was developed which would keep the potential of a rotating shaft within 5 millivolts of that of the hull, thus effectively grounding the shaft. This not only reduced corrosion of the hull but also reduced the radiated ELF signals.

A transmission electron microscope was added in 1969 and novel methods for replicating fracture specimens were developed. This fracture research also enabled the Laboratory to conduct electron fractography failure investigations on aircraft components from CFB COMOX, the first such work done within DND.

Most of the effort in inorganic chemistry was devoted to further refinements of methods to detect contaminants in lubricants, quickly and accurately. Spectrographic Oil Analysis (SOA) had been established as a valid system of maintenance control for ship's machinery. The SOA program was expanded to include all major ships within the Pacific Maritime Command. Exploratory studies were begun to establish the applicability of an SOA program to aircraft at CFB COMOX. Also, at this time, many sophisticated techniques were developed for the chemical analysis of various materials used in CF applications. For example a device for dissolving refractory materials was invented and patented (in the US and Canada) by Clint Waggoner and Doc Schmitz.

Research on paints concentrated on the problem of the adhesion of vinyl coatings to ships hulls.



The adhesion, performance and durability of paint and coatings are studied as a function of substrate conditions and exposure to weather

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Bob Chinnick returned to Ottawa in July 1969 to become Director of Personnel; he was replaced at DREP by Dr J.T. (Jim) Flynn.

1970 to 1978 - increases in acoustics and materials - DRB becomes CRAD

Organization, facilities and trends

Prior to becoming Superintendent at DREP, Dr Flynn held the same position at the Defence Research Establishment Ottawa (DREO). He possessed considerable experience in project management—including the leadership of the Canadian trials party participating in the 1956-nuclear weapons trials in Australia—which facilitated his making a number of substantial changes in the Laboratory's program and operations.

Drs Flynn, Ford and Sanders in Chiefs office at DREP

In 1974, NDHQ was reorganized with a much closer integration of civilian and military staff. Research and development in DND became the responsibility of the Chief of Research and Development (CRAD)[30] and shortly thereafter DRB ceased to exist. Another event which had a significant impact on the DREP research program was the formation of the Undersea Surveillance Co-ordinating Committee (USCC),[31] a committee which went a long way towards ensuring that the research program was consistent with CF requirements and supported at senior levels of the military. In research, the trend continued of emphasizing environmental investigations based on systems concepts. In the Arctic, where activity was

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[30] At the same time, the Laboratory Superintendents became Chiefs.

[31] The impetus for founding the Committee—chaired by either the Maritime Commander or the Chief of Maritime Doctrine and Operations and composed of CRAD, the Chiefs of DREA and DREP, and senior naval officers from NDHQ, the Commands, and the Washington Liaison Office—was the necessity to co-ordinate the military and research activities related to underwater surveillance in the Arctic. It quickly expanded its mandate to include surveillance in the Atlantic and Pacific, and was instrumental in co-ordinating the gathering of operational and research information on towed arrays, and the initiation of the various towed array system studies, one of which played a key role in the decision to develop the CANTASS towed array system for the CPF.

The first CRAD, Mr E.J. Bobyn, the ship's captain Stanley Bowles, and Dr Flynn board the ENDEAVOUR

increased substantially in both underwater acoustics and electromagnetics, this resulted in a change in emphasis in data gathering techniques from the periodic use of floating or ice-mounted sensors, to bottom-mounted sensors connected to shore stations to provide long-term continuous records of data. In the Pacific, the volume reverberation surveys were completed in 1972, following which, a substantial program was initiated in passive underwater surveillance using wide-aperture arrays. In fluid dynamics, the decision to concentrate on internal waves was implemented. Arrangements were made to shift the study of ocean turbulence to DEMR. Initially the DEMR staff operated out of DREP, thus affording mutual support between the two groups and to the project during the handover period. The work on MAD became almost exclusively devoted to signal processing to support and monitor contract development of an automatic MAD detection system for the Long Range Patrol Aircraft (LRPA).

The increases in level, direction, and scope of the research activities resulted in significant changes in the equipment and instrumentation required and put a large demand on engineering support. This was met by increasing the numbers of professional and technical support staff in the Engineering Section. Responding to increases in the size and frequency of field trials, the number of staff—particularly the professionals—were significantly increased in both Arctic and Ocean Acoustics. The level of activity and the number of staff devoted to Arctic research was further augmented by a decision to consolidate in one location all of CRAD's Arctic environmental studies, resulting, in the fall of 1976, in DREO's Ice Research Group being transferred to DREP. There was also an augmentation in the materials engineering staff. Since its inception, the Section had catered primarily to problems affecting naval construction and operations. Now a determined effort was made to undertake work more

Mr Bobyn demonstrates the finer points of ship handling to Captain Bowles

directly identifiable with the other two services. This led, in 1977, to DREP being designated the CRAD Establishment of Primary Interest (EPI) for Materials Technology—a development which contributed to an increased interaction with the DREA Dockyard Laboratory and the CF. It also resulted, in mid-1978, in the setting up at DREP of an Air Materials Group to look at problems related to the structural properties and battle damage repair of the composite materials in the CF-18.

Coping with these changes resulted in an increase in combined civilian and military staff from approximately 100 to 138. This in turn resulted in overcrowding of the existing facilities, which was alleviated by the construction of an enlarged photographic and engineering drafting facility on the north side of Building 199 and taking over Building 204, a temporary building situated across the playing field from Building 199. Early on, Building 204 was shared by the Materials NDE Group, the Ice Research Group, and the Base Chaplain. However, the 1977-decision to make DREP the EPI for materials engineering research soon resulted in an expansion of the DREP Materials Engineering program, and the occupancy of the entire building as a centre for activities in nondestructive evaluation and composites.

The increases in the Laboratory's research program and responsibilities also resulted in a number of organizational changes. In November 1973, a Physics Research Division was formed with Harold Grant as Director. It was responsible for non-materials related research and for providing engineering support to the Establishment's research programs. It consisted of an Electromagnetics Section—headed by Erwin Lokken—responsible for research in MAD and electromagnetic surveillance; an Ocean Physics Section—headed by Dr R.P. (Bob) Chapman[32] responsible for research in fluid dynamics, and underwater acoustics in both the Pacific and Arctic; and an Engineering Section—headed by John Smith who had recently taken over following Harry Davidson's retirement.[33]

In the fall of 1973, Al Milne, who had been the leader of Arctic Acoustics since its inception, left for IOS to manage a geophysical survey of the Beaufort Sea conducted jointly by the federal government and industry. His replacement for the next two years was Mr J.H. (John) Ganton. Then, following John's retirement, Mr R.A. (Rod) Hafer took over the leadership until September 1978 when he was transferred to Ottawa to manage the SARSAT project,[34] at which time, Jon Thorleifson became the Group Leader.

Interest in TTCP continued to expand with DREP providing the National Leaders for Subgroup P (Materials Technology) and several of its Panels and Working Groups, and the Subgroup G Panels on Sonar and Airborne Sensor Technologies.[35] This participation provided, not only an entree to the work going on in the US, UK, Australia and New Zealand, but contacts which were extraordinarily useful in supporting and advancing the Laboratory's programs, particularly in the area of towed arrays.

For many years, DND had provided the research ships required to conduct all the maritime research on the West Coast. However, as Fisheries and Oceans assembled their own fleet and contributed them to the Ship's Pool, the need for DND to supply two ships to the Pool became less compelling. Thus in 1976, when LAYMORE was retired, it was not replaced. ENDEAVOUR would, however, continue to play a key role in supporting West Coast experimental programs until the summer of 1995, at which time it was transferred to the East Coast.

During the time that Sir Charles was associated with the laboratory, there were very substantial interactions with Canadian, US and UK university staff interested in geophysical problems. With his final retirement, in 1968, these co-operative activities, with the notable exception of those at UVic, tended to die out. By 1973, contracting out, either to universities or industry, was making only a minor contribution to the DREP program. However, about that time, the Government had decided that any further growth in R&D would not take place in government laboratories but would be contracted out. Thus in 1974, a DREP Contracts

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[32] In order to bolster DREP's capabilities in ocean acoustics and to help expedite its participation with US laboratories in the September 1973 *Church Anchor* experiment, Bob Chapman and Jon Thorleifson had been transferred from DREA to DREP in July 1973. The former had an extensive—20 year—background in sound scattering in the ocean and in addition had served in various administrative capacities at DREA including Director of the Underwater Acoustics Division. The latter was a scientist with seven years experience in underwater acoustics research related to passive sonar, an area where DREP was then particularly interested in building up its expertise.

[33] Ashton Patterson later became Section Head on John's appointment to the Washington Liaison Office in November 1976.

[34] A major international search and rescue satellite project partnered by Canada, the US and France in co-operation with the USSR. By the end of its feasibility demonstration in 1985, it had been responsible for the rescue of nearly 500 people. One such incident, monitored by radio by DREP staff working in the North at the time, was the rescue of a US defence scientific party whose DC3 made a forced landing on an Arctic icefloe. Interest was heightened by the fact that DREP field parties worked fairly regularly with the principal scientist on board the aircraft. There was also a certain note of irony in that, though the Cold War was at its height, the rescue had to be effected using a Russian satellite.

[35] Harold Grant was the Panel Chairman for Airborne Technologies in 1972 and 1973. The following year, it became the responsibility of DREA. Bob Chapman was the Canadian National Leader of the Sonar Technology Panel from 1972 to 1995.

Officer—Mr A. (Tony) Moilliet—was appointed to expedite the process. The operation was quite successful in that the level of contracting quickly rose from $30,000 to over $3,000,000 per year. Although most of the money went to industry, universities also benefitted, with Materials Engineering placing contracts with several of the civilian universities and military colleges, particularly RMC. The results of these contracts provided much of the Canadian contribution to the TTCP Panels in Materials Technology. Although the contracts going out to industry were fairly well divided between large and small companies, they did have the effect of contributing substantially to the development locally of a number of small and enthusiastic companies engaged in marine science. These companies were later to come under considerable pressure with the closing of DREP.

Ocean Acoustics

In 1971, two surveys were conducted of the sound backscattered from biological organisms in the Northeast Pacific. One covered latitudes between the southern tip of Vancouver Island and Hawaii, and the other the area to the north, the Gulf of Alaska. The technique developed earlier, using an explosive sound source and omnidirectional hydrophone, was used to observe the scattering strength of the water column with its striking changes associated with acoustic frequency, water mass and time of day. With the completion of the analysis of these data, DREP acousticians focussed their interest—more or less permanently—away from problems associated with active sonar and on to passive sonar.

This change was in fact underway at the time of the northern reverberation survey. Arrangements had been made to have ENDEAVOUR rendezvous with the USNS SILAS BENT and USNS BARTLETT to participate in a US NAVOCEANO acoustic survey of the Northeast Pacific. A long-range propagation run was carried out with ENDEAVOUR and SILAS BENT anchored, while BARTLETT, dropping charges, opened range to 400 miles. A second set of measurements along the same track was obtained with the aid of an Argus aircraft dropping SUS charges.[36] This experiment provided an excellent demonstration of ENDEAVOUR's deep anchoring capability which had been developed by DREP and which permitted position to be maintained over long time periods in deep water—in this case, 75 hours and 5050 metres.

The year 1973 marked the change in direction in ocean acoustics research, as well as the beginning of a buildup in resources applied to this area. The white paper on defence, *"Defence in the 70s,"* stressed the major role of the Canadian Forces in the surveillance of Canadian territory, coast lines, and the ocean approaches thereto, both as a requirement for the protection of Canada and Canadian interests and as a contribution to North American defence. Therefore, as there was little information available relating to the performance of long-range, passive acoustic surveillance and detection systems in the MARPAC area of the Northeast Pacific, a research program relating to this subject was developed. The objective was to provide a detailed description of the characteristics of propagation and noise in the ocean, particularly their directional properties, which are required to estimate the performance of wide-aperture surveillance systems. In order to determine the horizontal directional properties with sufficient angular resolution, it was necessary to employ large-aperture arrays in the measurement program. It was decided to meet this requirement by acquiring a long-line, oil-filled towed array similar to those used in seismic prospecting. A second reason for acquiring and developing an expertise in the operation of these arrays was that they could be made available to the Canadian Forces for training and operational exercises.

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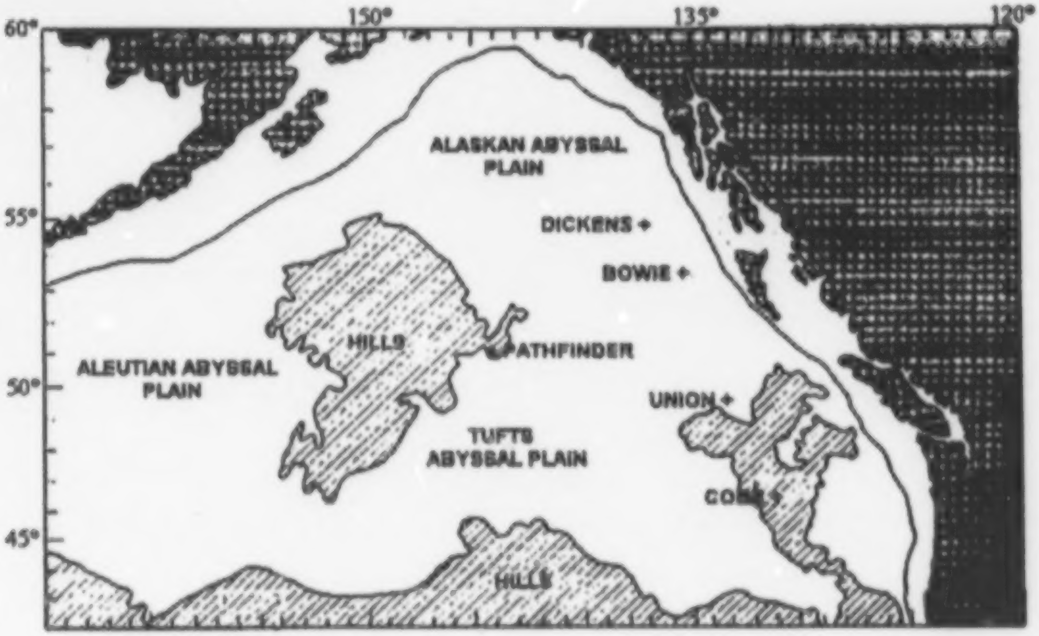
[36] An air deployable charge containing 0.8 kg of explosive.

As a first step in the program—and well before the acquisition of the towed array—DREP and aircraft from MARPAC participated in September 1973 in the low-frequency acoustic experiment, Church Anchor, along with several US agencies. In the course of the experiment, DREP scientists used a multi-element superdirective array, designed by Jon Thorleifson, to measure propagation loss and ambient noise and its horizontal directivity at two locations in the Gulf of Alaska. A pronounced drop in signal level was observed when sound sources passed over the Pathfinder Seamount. Having identified seamount shadowing as a problem, and as seamounts are a common feature in the Gulf, more detailed investigations of this phenomenon were conducted over Bowie and Dickins Seamounts, in 1974 and 1975 respectively.



Seamounts and abyssal plains investigated acoustically

ENDEAVOUR, LAYMORE and Argus aircraft participated in these experiments. The sound sources were SUS charges dropped from the Argus and a CW-projector towed by LAYMORE. The receiver was the newly designed Multi-Element Volume Array (MEVA), a free-floating, radio-telemetry buoy which included both horizontal superdirective and vertical line arrays. The data were telemetered to and recorded on ENDEAVOUR. The investigation at Dickens produced two well-received papers,[37] the results of which were incorporated by the USN as standards in their acoustic modelling suite. Ambient noise measurements made on these experiments showed well defined directional patterns with the highest levels along the main traffic routes either through the Gulf of Alaska to Asia or along the Pacific Coast.

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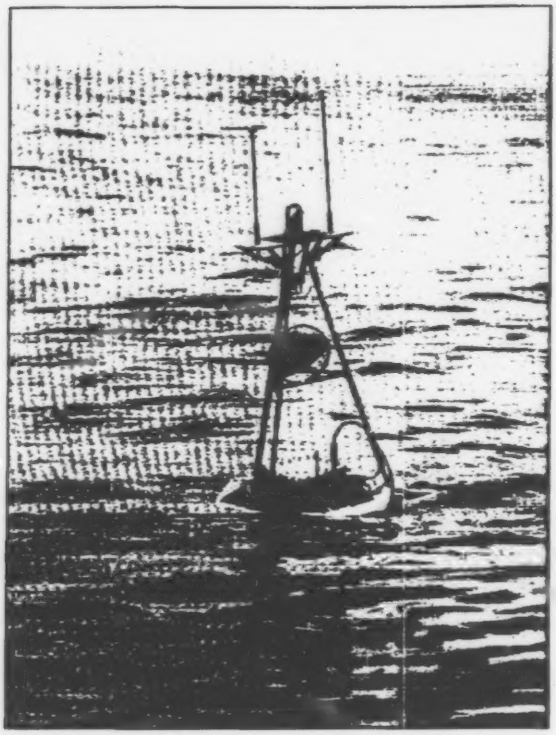
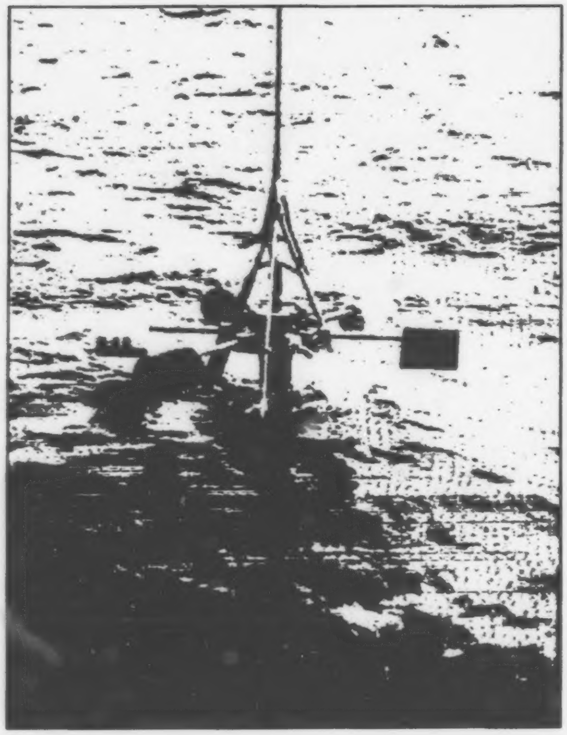
[37] Gordon Ebbeson was the principal analyst and senior author.



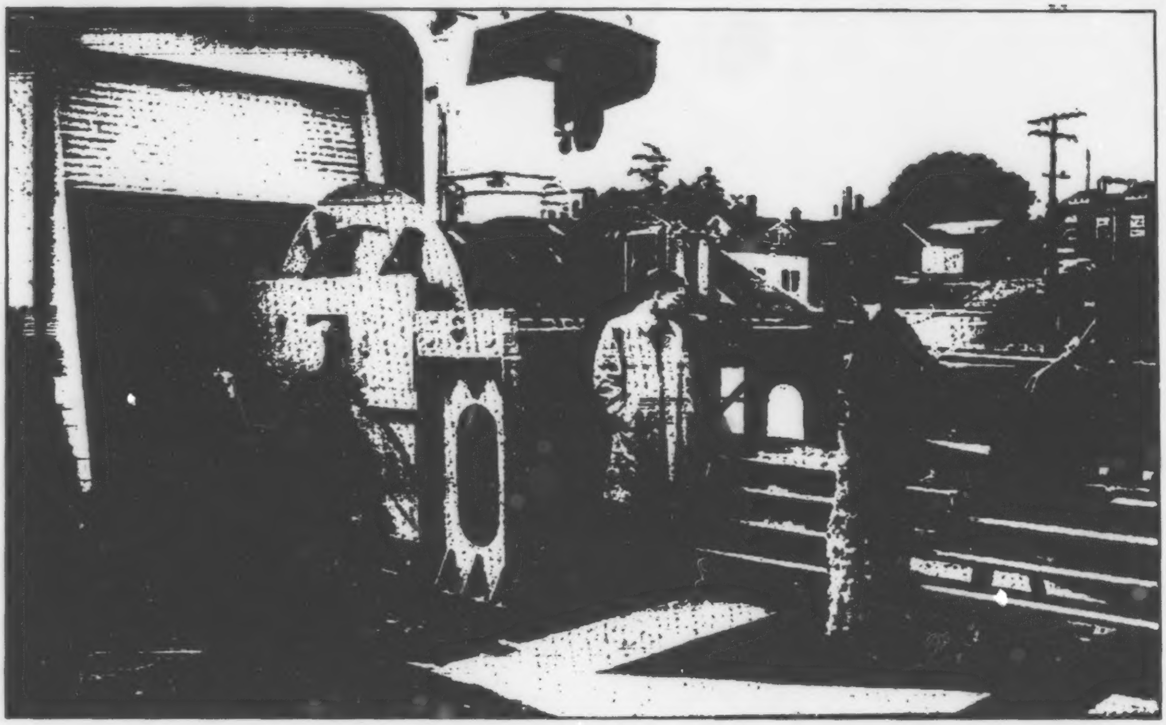
MEVA's surface buoy



Lowering MEVA's horizontal array

MEVA continued throughout the duration of the project to be the principal research tool for sound propagation, and for those ambient noise studies where limited resolution would suffice. Experiments were carried out in the Gulf of Alaska in both 1976 and 1977. The sound sources were explosive charges deployed from, in 1976, an Argus aircraft and, on two trials in 1977, CSS PARIZEAU. This initiated a very successful study of the reflection losses of the ocean bottom and the creation of geoacoustic profiles of the subbottom to explain the observed losses. This investigation also included high quality measurements of the source spectrum levels of the various charges used in the program. The scaling laws, developed by Dr N.R. (Ross) Chapman to relate spectrum levels to charge weight, achieved wide acceptance in the underwater acoustics community and have now become standard in underwater acoustic studies involving explosives.

In undertaking a program of research related to underwater surveillance using towed arrays, DREP received much encouragement and material support from other countries, particularly the US. Beginning in 1972, and for the next two decades, towed arrays was a theme topic at the annual meetings of TTCP GTP-9, the SONAR Technology Panel. This assisted DREP in quickly coming up to speed in towed array technology. In addition, the US National Leader on the Panel also held the senior civilian position at NAVSEASYSCOM and hence was in a position to be extremely helpful in assisting DREP to borrow equipment from the USN or to purchase it from the US defence industry. As an interim measure, while negotiating and waiting for the delivery of a seismic exploration type array, NAVSEASYSCOM provided DREP with the most usable components from three recently-retired ITASS (Interim Towed Array Sonar System) arrays. They arrived at DREP in early 1975. After undergoing extensive refurbishment, they were combined into a workable system, which proceeded to a workup trial



Glenn Turner and Jon Thorleifson with ITASS on ENDEAVOUR's helicopter deck

at sea in October.[38] Its performance exceeded expectations. Although replaced in 1977 by the seismic array, it served usefully as a backup for the next decade.

As pointed out earlier in connection with flow noise, fluid dynamics and scale modelling of acoustic propagation, the fiords and channels of the West Coast possess features that are extremely well suited to many kinds of investigations in marine science. This was the compelling reason for the US and Canada setting up an underwater test range at Nanoose, a facility often used by DREP in support of its various projects. However, for the towed array program, the test area of choice was Jervis Inlet. It is well within easy sailing distance from the Laboratory, with very low ambient noise and with deep, sheltered, long reaches, in other words, an ideal location for testing towed arrays. Over the years, it became the practice to spend the first few days of field trials involving either towed arrays or MEVA in grooming the systems in Jervis Inlet. This, combined with the fact that Mr R.W. (Bob) Chappell usually participated in the grooming, undoubtedly contributed to the low level of down time experienced at sea.

The self noise of ITASS was measured as a function of towing speed during the trials in Jervis Inlet in October 1975. Similar measurements, made during the follow-on workup at sea, indicated that ITASS would be a very satisfactory interim tool for conducting research in ocean surveillance and bringing first hand experience in towed array operations into the Department. The array was used in three operations in 1976 to measure array performance and ambient noise directionality at several locations in the Northeast Pacific. The resulting noise patterns were consistent with those obtained with MEVA, but with the much higher resolution resulting from the 146-m aperture of the array.

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[38] The refurbishment carried out by Bob Chappell and his associates was extremely well done. Never in its operational life had ITASS worked so well. This was attested to by a USN sonar specialist who participated in the first workup trial. He found it a very emotional moment seeing the system finally operate as it was designed to do.

In March and May 1977, detection runs were made using a sound source mounted on the submarine HMCS OJIBWA, with the signals being received on the ITASS installation on ENDEAVOUR. Members of the MARPAC acoustic analysis team and operational research staff participated in these experiments in order to obtain first-hand experience in towed array operations.

The COAMS (Canadian Ocean Acoustic Measurement System) towed array was delivered in March 1977 by Hydroscience Inc of Dallas, Texas. Preliminary trials, carried out in June and December, showed self noise levels which were significantly lower than those of ITASS, reflecting the substantial improvements that had taken place in towed array technology over the previous decade. In May and November 1978, COAMS was used to study the directional noise field at a representative location in the Northeast Pacific, the results reflecting the increased resolution achievable with the 1,220-m array. In September, DREP and MARPAC staff co-manned the towed array installation on ENDEAVOUR in a major military training exercise, thus continuing the very rewarding cooperation with the local military forces in towed array operations which, with the exception of one period when ENDEAVOUR was undergoing an extensive refit, became essentially an annual event.

In late 1976, DREP acted as the EPI for the CRAD-initiated TACTASS Study carried out in support of the Canadian Forces Ship Replacement Program. The study, aimed at determining the usefulness of tactical towed arrays in meeting the nuclear submarine threat till the turn of the century, had two objectives, the first being to evaluate the technical performance of towed array systems and their impact on ship specifications and the second to investigate their operational application. The study involved a number of other CRAD laboratories, operations research, and a number of NDHQ directorates, each contributing in its area of expertise. It was concluded that tactical towed arrays would provide a useful capability to the Patrol Frigates. This conclusion was acted upon by the Navy who subsequently launched the CANTASS towed array development program. In later years, there were a number of other studies relating to towed arrays, mostly associated with possible submarine acquisitions. Because of their demonstrated expertise, DREP scientists invariably took a substantial, often the leading role, in these activities.

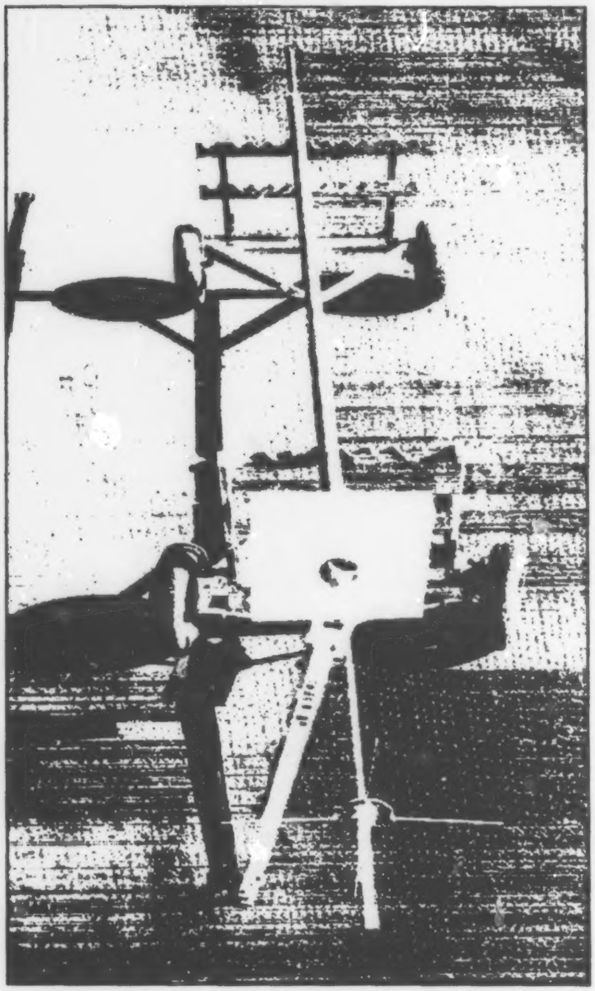
A heavy involvement in systems studies requires an extensive acoustic modelling capability. This was recognized at the time the underwater surveillance program was being considered and, by 1975, steps were taken to develop a substantial propagation modelling facility at DREP. In due course, a suite of the most useful propagation models developed in the US and at SACLANTCEN was assembled. In addition, research was carried out in-house on propagation modelling, particularly that related to the Parabolic Equation (PE), a model with speed and accuracy sufficient for it to be employed real-time at sea. Dr D.J. (Dave) Thomson subsequently became a world recognized expert in this area, with many innovations to his credit.

Arctic Acoustics

The earlier measurements in the Arctic channels indicated that ambient noise levels were low, particularly under shore-fast ice and in the absence of pronounced changes in air temperature. Sound propagation was relatively good, consistent with the generally isothermal water conditions found throughout the Arctic. Thus conditions were favourable for the passive detection of submarines going through the three potential transit routes: east-west via Parry Channel through Lancaster Sound, Barrow Strait, Viscount Melville Sound, and M'Clure Strait; the main north-south route through Robeson Channel; and the alternative north-south route through Fram and Jones Sounds. How best to exploit the detection possibilities in these transit routes was the focus of the Arctic research program for the next several years. A number of possibilities were considered, including mounting sensors on the ice and interrogating them from aircraft, or using either arrays or lines of single hydrophones cabled to shore. Evaluation of these possibilities and any follow-on design and development required a fairly detailed knowledge of the acoustic and other environmental features of the various channels. From 1970 to 1978, effort was concentrated on making the necessary measurements, gaining an overall appreciation of the problem, and coming up with a range of systems options for consideration by the Canadian Forces.

Based on earlier work, DREP scientists had sufficient knowledge of the acoustic and environmental conditions to design the essential experiments. They had also developed a considerable expertise in working in the Arctic and in specifying, designing, constructing, and testing equipment for operation in the extreme cold. Logistic and system installation problems were, however, formidable and addressed only through the generous co-operation of the Canadian Forces and other government departments. Eventually, performance testing of the underwater installations was required, necessitating the use of mobile underwater sound sources. In open water conditions, such as those found in summer in Barrow Strait and Jones Sound, sound projectors towed from surface ships could be used. Mobile sources for use under heavy ice cover—nuclear submarines—were not available in Canada, so this resulted in 1977 and beyond in significant co-operation with the USN and their associated naval laboratories.

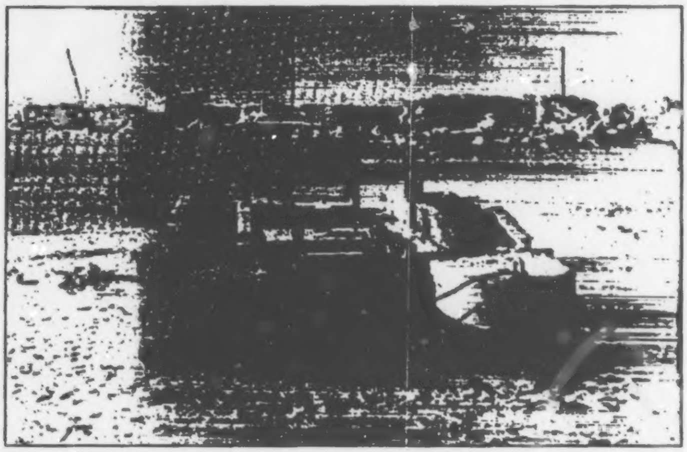
In April 1970, twenty sono-drift buoys were installed in both annual and heavier polar ice in West Parry Channel. Data on ambient noise and buoy position were gathered on weekly to bi-weekly patrols of CF Argus aircraft until mid-October, by which time the last of the buoys failed to respond. It was observed that the buoy positions were relatively stable but that attrition was particularly high in those buoys mounted in annual ice. It was concluded that it would be feasible to operate buoy fields of this type for about eight



Arctic sono-drift buoy on cart

months of the year. Due to the desirability of year-round coverage, no further investigation of this concept was undertaken. Thus a decision was made to look at the problem of surveillance using bottom-mounted arrays or lines of well spaced single hydrophones. The sensors, connected to shore, would permit, experimentally, very long time series of the ambient noise background and, operationally, year-round surveillance. One of the most frustrating problems associated with the use of shore stations was protecting cables from destruction at the land-sea interface. A number of approaches were tried including laying cables along river deltas, where they could sink into soft mud, and trenching through the beach. Varying degrees of success were experienced but in some areas failure was almost an annual event. Barrow Strait was a particular problem; some years not only the cable disappeared but the beach as well. Thus cable repair and maintenance became a standard feature of northern deployments for the next several years.

A second problem arose from the fact that the ambient noise background in the Arctic is lower than that found in other oceans, sometimes by several tens of decibels. In order to take full advantage of this beneficence of nature, it is necessary to use hydrophones that are unusually unresponsive to flow noise. As this is much less of a consideration in other ocean areas, little research had been done on the problem. The search for a solution to the problem was not without interest, and eventually successful.



Catamaran used for cable laying in Robeson Channel

In April 1971, Mr J.A.F. (John) Wilson, a mechanical engineer responsible for the design, construction, and installation of DREP's underwater facilities, installed hydrophones on the bottom at Wrangel Bay in Robeson Channel. This was very successful in that the hydrophones remained operational and maintenance free for many years. Propagation loss measurements were made to these hydrophones using, in August 1971, explosive sound sources deployed from the icebreaker LOUIS ST LAURENT and, in 1974, a CW-source deployed from an icecamp. The next area for concentrated effort was Barrow Strait. As a result of a reconnaissance in August 1971, and a more detailed survey carried out from the LOUIS ST LAURENT the following year, Gascoyne Inlet on Devon Island was chosen as the optimum site, having a protected deep-water bay, a camp area with water, and adjacent high land from which to launch telemetered data to Resolute Bay. Also in 1972, two RIP packages were installed south of Devon Island for recovery the following year. In 1973, all of the DREP Arctic effort was applied to this channel. In April, ambient noise and sound propagation measurements were made at an icecamp. In August and September, a DREP-designed system was installed and connected to shore using the icebreaker SIR WILLIAM ALEXANDER. The system consisted of simple 6-element horizontal and 3-element vertical acoustic arrays mounted on the sea bottom, cables to bring the signals ashore, and a microwave link to a recording and analysis centre at Resolute Bay.

Silo housing telemetry equipment and batteries being installed at Gascoyne Inlet

Silo covered with ice, but it still works

Beginning in 1974, annual NORPLOY expeditions, conducted by the Maritime Command in Halifax, contributed substantially to the DREP Arctic research program. The first year, sound transmission was measured using explosive charges dropped by a Sea King helicopter, with the sound received by a hydrophone suspended from the supply ship, HMCS PRESERVER. Activity picked up considerably the following year when HMCS PROTECTEUR conducted the northern deployment. On this occasion, a 7-element horizontal array, specifically designed to reduce flow-induced noise, was installed[39] and the Navy owned submersible *SDL-1* was deployed from PROTECTOR to survey the bottom and to examine the condition of the underwater cables connected to the various arrays. Although the cables deployed the previous year had survived through 1974, they were broken by ice movement in the spring of 1975. Repairs were effected with the assistance of Navy divers, who also conducted extensive trenching activities to protect the cables at the land-sea interface. DREP, along with other government agencies and universities, also participated in NORPLOY 77, where *SDL-1*—transported by HMCS PRESERVER—was used in the repair of the cables of the experimental array.

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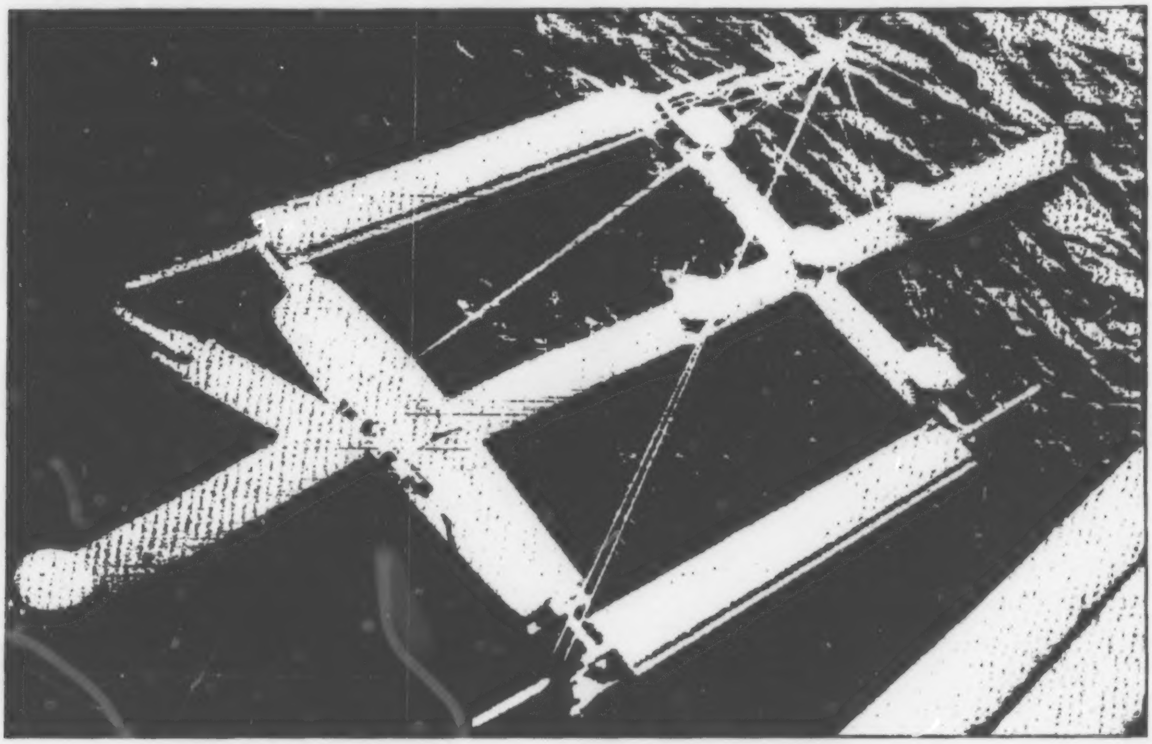
[39] The low-profile, smooth-faired array, employing hydrophones mounted in thin water-filled oblate spheroid enclosures to reduce their susceptibility to turbulent flow, improved the situation but still fell well short of what was required for maximum exploitation of the low-noise conditions found in the area.



Arctic array being launched from PROTECTEUR

As modifications to underwater installations in the Arctic could be made at best annually, and at considerable expense in terms of personnel and logistics, it was decided to try and solve the flow-noise problem locally. Portable arrays were constructed in which side-by-side comparisons could be made of hydrophones using different and readily changeable enclosures. In 1977 and 1978, an appreciable effort was made to find a suitable test site in waters near Victoria. A total of 14 locations off Vancouver Island and the mainland were investigated in order to find locations which best mimiced the Arctic Channels in terms of noise level, current, and other environmental conditions. Eventually, the search led to Chatham Channel, well isolated from the open ocean, with essentially no marine traffic or industrial activity, all conditions conducive to a very low ambient noise background. Currents were relatively high but cycled with the tide so that any desired speed was readily available. Also the water depth, rocky bottom and isothermal water conditions were not untypical of those found in Arctic channels. In short there was—except for the ice cover—an ideal test site in the local area, which simplified the problem considerably and speeded up its solution. The ideal enclosure turned out be flat, low profile, with the hydrophone in a water-filled flexane-covered steel frame wrapped with an open-celled foam. This design was used in all subsequent installations where very low self noise conditions were required.

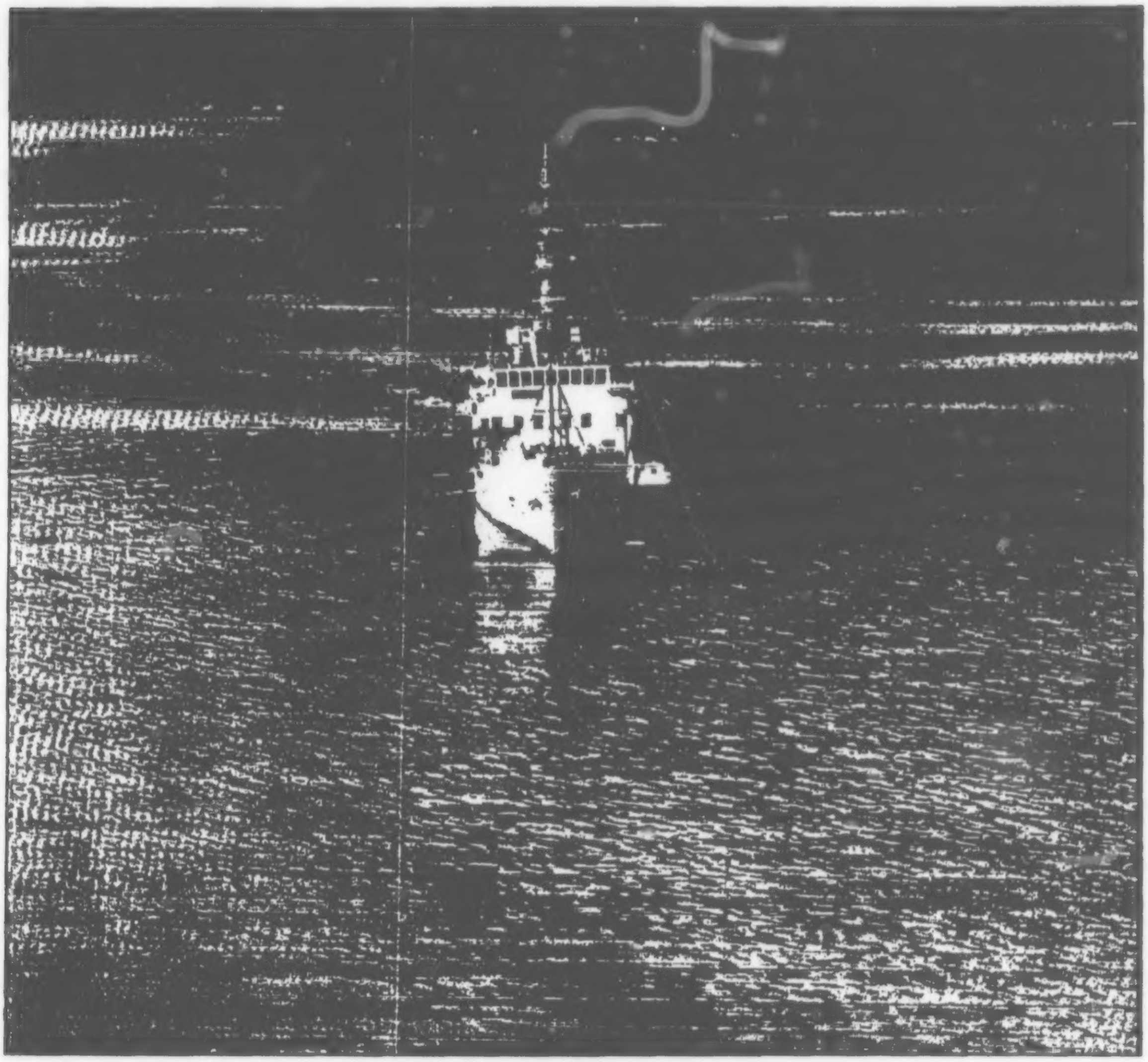
From 1976 to 1978, DREP vigorously pursued the investigation of underwater phenomena which affect the performance of passive detection systems in the Arctic; in six expeditions to Barrow Strait, measurements were made of ambient noise, sound propagation and their effect on array performance. In addition, noise coherence and array performance were recorded on a continuous basis. Knowledge of the bottom in the area had been increased through work carried out in 1976 by CSS HUDSON in co-operation with the Marine Coastal Section of DEMR. Air gun reflection surveys and ancillary measurements were carried out to determine compressional and shear wave velocities, and bottom and sub-bottom roughness. These measurements were used later in propagation modelling at DREP to account for an interesting propagation anomaly observed at low frequencies. HUDSON also assisted by towing a sound source during an experiment to measure the signal coherence of a moving source. A second experiment to measure signal coherence from a moving source was carried out the following spring in co-operation with NRL. The object was to compare measurements made in the same area under open water and first year annual ice. It was concluded that although the effect of rough multi-year ice on sound propagation is quite significant, that of relatively smooth annual ice is not. Generally, the experiments being carried out were no longer surveys but were designed to answer specific questions such as the effect of seasonal changes of water temperature near the surface on sound propagation.

The transit route through Jones Sound was given the least priority and this was reflected in a lower level of experimental activity. In 1972, an Argus aircraft dropped a sonobuoy at Hells Gate, at the western end of the Sound, to monitor ambient noise levels. During NORPLOY 74, three single hydrophone packages were laid on the bottom by landing craft, with cables running ashore to data logging recorders to obtain year-long time-series of ambient noise. Sea King helicopters dropped SUS charges, and sound transmission was measured both to the bottom-mounted hydrophones and to a hydrophone suspended from PRESERVER. In April 1976, sound propagation measurements were made in an area south of Grise Fiord for comparison with those made two years earlier in open water conditions.

By 1977, the investigations in the various channels had progressed to the point where it was possible to come up with a realistic assessment of the surveillance problem and to make recommendations for its solution. A study was completed in 1978. Some time later, this was followed up by DND going out to industry for design proposals for systems to monitor the transit routes. However, when the winding down of the Cold War reduced the priority of northern surveillance, implementation was placed in abeyance.

Fluid Dynamics

A study was completed on the surface currents to be expected from submarines operating in Canadian waters. Results were presented to the DRB Program Review Group in May 1970 where it was agreed that, as the physical processes that occur at the surface were not well understood, future research should concentrate on the factors which determine the visibility of internal waves. Accordingly, experiments were conducted in July 1971 in Bute Inlet and Georgia Strait to examine the factors affecting the visibility from the air of internal waves. The internal waves were generated by ENDEAVOUR moving at slow speed and the properties of the wave field were measured by the same vessel. Photographs of the wave field were taken from a helicopter. The 'visibility' was plotted against the obvious independent variables in a search for significant correlations. The following year, an experiment, which included the direct measurement of sea surface slopes, was carried out in Bute Inlet to enlarge the data base. As a result of these experiments, a relationship was found between rates of change of wave slope, current, and wind speed. A mathematical solution to the problem was obtained which provided a general substantiation to the measurements and an understanding of the mechanisms involved. In addition, calculations were made of the optical sensitivity of the glitter pattern to internal wave surface currents. A contract was then let for a study of the potential development of a combined illumination source and detection system for active measurement of sea surface glitter patterns from an airborne platform. Then, the project was placed in abeyance as, in mid-1975, Blyth Hughes, the principal investigator, departed for a one-year sabbatical to the Scripps Institute of Oceanography to work on problems in underwater acoustics.



ENDEAVOUR departing internal wave field

On his return, he concluded that although an optical system would be an effective research tool for investigating the modification of the sea surface by internal waves, any practical implementation in a detection system would probably have to be based on radar. Accordingly, in July 1978, he participated in an experiment to compare radar measurements from a satellite (SEASAT-A) and an aircraft with surface truth measurements of wind waves that had been modulated into patterns by internal waves. The measurements were taken in the waters between Vancouver Island and the mainland, those at the surface being made jointly by the Institute of Ocean Science at Patricia Bay, and DREP. The radar data were made available by NASA and the Canadian SURSAT Project Office.

Electromagnetics

In March 1970, the DREP/NAE report on Magnetic Anomaly Detection was submitted to DRB. As a result of the recommendations in the report, co-operation with NAE and industry in activities leading up to the development of operational MAD systems intensified. Over the next several years, the DREP program focussed on the development of automatic detection algorithms, the collection of the background noise data required in their design and to estimate system performance in areas of operational interest, the identification of the sources of noise and their impact on system performance, and the advantages of including gradient information in MAD systems.

At the time, an automatic computer-based MAD signal processing system had been developed at Computing Devices of Canada, under contract to the Department of Trade and Commerce and the USN. DREP installed the system on its computer and tested it performance with MAD noise records of various types, including geological, micropulsation, and swell. Particularly useful in this investigation were the data collected at DRES in 1970 on specially designed micropulsation equipment.

In 1973, Mr R.E. (Roy) Erickson—recently transferred from DREV—began an investigation of computer-aided MAD detection. The objective was to monitor progress on a CF contract for the development of an automatic MAD detection system for the proposed new Long Range Patrol Aircraft (LRPA) and to provide technical consulting services to the CF and the contractor. During 1974, considerable progress had been made in evaluating the capability of a Wiener prediction filter based detection algorithm. Performance comparable to that of a human operator was achieved on simulated target and noise data. This system combined the advantages of not requiring a detailed target model with computational simplicity. The contractor, CAE, then pursued a detection algorithm using a Wiener Predictor as a threshold detector followed by a classification routine. At DREP, the investigation of new techniques in signal processing continued, with emphasis on the maximum entropy approach. Two years later, when CAE encountered practical limitations to the Wiener prediction algorithm—adaptation times were from 30 to 60 minutes, while the alternative had been demonstrated to adapt in an operationally useful 2 minutes—they abandoned this approach for that of maximum entropy.

DREP was then tasked by the CF to design an adaptive signal processor which could provide an optimally filtered time series output of the MAD signal on a display suitable for operator interpretation. It was also to include features for transient noise suppression and target range estimation. The resulting processor—using a modified version of maximum entropy spectral analysis for the adaptive signal whitener and the range estimation algorithm—was implemented on the Laboratory's central computer. Following successful testing, an airborne system, based on a commercial minicomputer, was then developed at DREP for testing on the Maritime Proving and Evaluation Unit (MP&EU) Argus.

To support algorithm development and to estimate system performance, a high quality data base of the electromagnetic background is essential. Throughout 1970, micropulsation data were collected on the specially designed equipment operated at DRES. In April and May, it was augmented by additional detectors operated by DREP, while the NAE North Star MAD research aircraft collected complementary information on flights over southern Alberta. In the next few years, several flights on both coasts, the most extensive with DREP scientists on board, were made with the North Star—fitted with an optically pumped caesium vapour magnetometer and a compensation system to reduce aircraft induced noise—to expand the data base and to identify noise sources. In 1974 and 1975, recordings were made of the magnetometer output, and aircraft displacement, rotation and acceleration in the MAD pass band. A comparison of these data with measurements made simultaneously at a shore station led to the identification of the various noise sources associated with geology, micropulsations and aircraft translations. The next year, experiments were carried out off Bermuda using the submarine HMCS OKANAGAN.

The geographic coverage of data collected in collaboration with NAE was augmented considerably through efforts of the CF. Beginning in 1970, Argus aircraft collected geological noise data in the Arctic during their northern patrol flights. In 1971, similar measurements were carried out in the North Pacific using a P3C Orion and a Nimrod. In 1975 and 1976, DREP participated in tests of the performance of the magnetometer and fully automatic compensation system (FACS) in the MP&EU Argus. On one of these trials, in 1976, OJIBWA served as a target thus permitting interesting comparisons with OKANAGAN. Further measurements were made off the West Coast in 1976 and 1977 to select an optimum test area for 407 Squadron of CFB COMOX to evaluate the performance of its MAD systems. Intuitively, the best areas would be in deep water as the geological material is further away from the aircraft. However, off the West Coast, subduction of the Juan de Fuca tectonic plate forces bottom material to slide under Vancouver Island, the result being that the more magnetic material—formed on the sea floor by volcanic action—is actually deeper in shallow than in deep water. Accordingly, their test area in deep water was abandoned and replaced with one in shallow water quite close to the Base. As the noise levels in the Argus were slightly lower than those in the North Star, the data obtained with it on the various trials provided a useful addition to the data bank. This information received extensive use both in-house and by contractors developing equipment and algorithms for the CF.

Computer programs to evaluate MAD performance were in place by 1971, and were refined in later years. In 1975, MADSIM, a program to simulate MAD-equipped aircraft flights, became operational, its initial objective being to provide a less costly tool than aircraft flights for the development and evaluation of detection algorithms. Realistic target signatures, flight manoeuvres, geological noise, manoeuvre-related noise and geomagnetic micropulsations were simulated or added from recordings. The simulated manoeuvres included both deterministic and random components. The program was later refined to permit interactive operations. It thus became a powerful tool not only for testing signal processing algorithms but also for tactical and operational research studies and operator training.

In 1973, DREP responded to a request from the LRPA Project Office to participate with NAE in an evaluation of the relative merits of single and dual wing-tip magnetometers for magnetic anomaly detection. The study indicated that dual MAD would be superior to single MAD in cases where geological noise or geomagnetic micropulsations were the limiting noise sources. This would be reflected both in a modest increase in detection range and a clear left-right indication of target position. The most serious problem would be compensating for flexing of the wings. Although dual MAD was not installed on CF aircraft, it did focus attention on directional MAD. The following year an investigation—through a contract with Canadian Thin Films (CTF)—began of the long term potential of superconducting magnetometer technology. Superconducting magnetometers through their ability to measure magnetic gradients very precisely have the potential both to provide localization information and to enhance detection ranges in noisy environments. It was concluded that a system based on a five-component superconducting gradiometer and a three-component superconducting magnetometer would be feasible and that airborne experiments should be carried out to verify the calculations and to gather background geological-noise gradient information for signal processing studies. In 1976, a follow-on contract, funded by DEMR, was let to CTF for the construction and testing of a three-component gradiometer. DREP was to provide the data recording instrumentation for the system and to assess, based on the performance of the three-component gradiometer, the desirability of extending the contract to include a full five-component system.

Investigation of the technology associated with underwater, bottom-mounted electromagnetic barriers continued, with emphasis on cancellation techniques to reduce background noise and hence to increase detection range and reliability. As the application of such systems is largely confined to shallow water in proximity to a shoreline, it was noise cancellation under these conditions that received the bulk of the attention. The analysis of micropulsation coherence across sea-water interfaces was readdressed. The data indicated that micropulsations and ELF signals detected at sea, perhaps only a short distance from the coast, though coherent in general with those on land, could differ greatly in amplitude and phase. Nevertheless, for a fixed point in the sea area, and another on land, time-invariant factors could be determined to relate the one with the other, thus allowing the possibility of micropulsation and ELF noise cancellation with a fixed detector installation.

In 1970 and 1971, signal processing studies were conducted, cancellation techniques were devised, and very encouraging results were obtained on data collected on the earlier studies. It was then decided to continue development and to demonstrate their effectiveness at the Nanoose Tracking Range and at Assistance Bay off Barrow Strait. Nanoose provided the possibility of testing the techniques on interesting targets while Assistance Bay would permit the examination of the effects of ice cover. In 1972, in connection with a model study, an experiment was conducted at Assistance Bay which indicated that there were no major phase shifts within three miles of the shore, and hence it should be an ideal site to test a line of bottom-mounted sensors. A short array was to be installed in the summer of the same year. However, late arrival of the icebreaker due to other duties and developing ice conditions prevented its installation at that time. The array was returned to the south and installed at Nanoose the following spring. In August, a similar array was successfully installed at Assistance Bay. The noise cancellation on both of the arrays exceeded the minimum estimates. In April 1974, a major experiment was conducted using a sensor on the shore at Assistance Bay and two on the ice offshore to examine the effect of sensor spacing on noise cancellation. In the summer, the performance of the bottom-mounted array was retested using a subsurface dipole source towed by a Sea King helicopter from HMCS PRESERVER.

By 1975, the basic principles of effective noise cancellation had been established. Research then concentrated on the computational and instrumental factors limiting noise cancellation, on towed source measurements, and on possible operational array design. In addition, a start was made on real-time noise cancellation. A theoretical investigation of the effect of an irregular coastline on the geomagnetic micropulsation background was completed and published.

In 1976, considerable effort was devoted to improving noise cancellation at the lowest frequencies. This involved replacing the zinc electrodes which had been used up to that time with the quieter silver-silver chloride electrodes. Also considered were the advantages to be obtained from an additional reference electrode situated well off shore in the deeper water. These, and other improvements resulting from extensive simulation studies, were tested the following year in experiments at Assistance Bay. A very successful ice-mounted experiment was conducted which tested a number of coherent noise cancellation methods. The availability of a mini-computer-based analysis system at nearby Resolute Bay enabled the main noise sources to be quickly identified and corrective action taken. The real-time subtraction of the micropulsation noise using the modified reference system proved to be particularly effective, the residual noise level being reduced effectively to that of the system itself.

Work had also been progressing in the ELF countermeasures field. A DREP patented shaft-grounding system, installed on ENDEAVOUR and tested on the range at Nanoose, showed a very substantial reduction in radiated noise when compared with that of the ungrounded shafts.

Materials Technology

A high level of activity was maintained in addressing day-to-day problems, consulting and long-term research. One problem of particular interest arose from the grounding of the oil tanker, ARROW, in 1970. Some time earlier, Dick Sewell had invented the Slick-Licker, a device for removing oil from the sea surface. In response to a request from Dr Harry Sheffer, the VC/DRB and organizer of the DND contribution to the cleanup, the Slick-Licker was tested for its ability to remove Bunker C fuel oil off water at 0°C. These trials, involving removal of oil with consistency comparable to that of molasses, demonstrated that a removal rate of one barrel in about two minutes was feasible even with a viscous oil. With this proof of capability, the DREP unit was shipped to Chedabucto Bay, NS, to participate in 'Operation Oil.' With the assistance of DREP personnel, this unit, plus three others built in the East, contributed in fair measure to the task of picking up the oil and oil-soaked seaweed resulting from the ARROW spill.

Slick-Licker tests at Colwood

Dick Sewell demonstrates the Slick-Licker to the Hon Robert Stanfield, Leader of the Federal Opposition

Dick Sewell receiving a cheque from Dr L'Heureux—the last Chairman of DRB—for his contribution to the ARROW cleanup

Another impact on the East Coast at this time grew out of the Spectrographic Oil Analysis Program (SOAP) conducted by Clint Waggoner's Group. DREP had trained naval personnel and participated in the installation of a spectrometric analysis facility on HMCS YUKON—later transferred to the supply ship HMCS PROVIDER. Following a successful demonstration of its effectiveness in a Far East operation, drawings and instructions were provided to NDHQ to facilitate comparable installations aboard the East Coast supply ships HMCS PRESERVER and HMCS PROTECTEUR.

At this time, experiments were also conducted in the use of solid abrasives for stripping paint from metal surfaces. Finely divided ice particles were supplied through a cold chamber to a blast nozzle for removal of mill scale and rust off steel plates. Even though not as effective as grit or sand blasting, the method showed considerable promise, particularly for special applications where grit or dust would be inadmissible. A considerable amount of effort was devoted to the development of this technique over the following years. Its most successful application turned out to be the removal of paint from aircraft fuselages, an activity where the competing processes cause unacceptable damage.

Evaluation, in Jack Carson's Group, of an electronic device for maintaining low shaft-hull electric field potential, in order to reduce corrosion of the ship's hull, was demonstrated on HMCS MACKENZIE, and proved to be both effective and reliable. As this technique was also effective in cutting down low-frequency electromagnetic radiation, it was later adopted by the Establishment's program in mine countermeasures.

Effort continued, in Frank Peters' Group, on the use of ultrasonics for determining wear in superheaters and boiler tubes. A contract was let to Canadian Thin Films (CTF) to evaluate the feasibility of making the process semi-automatic. When this appeared to be an attractive proposition, a follow-on contract was let to the company to build a working prototype, the construction of which began in 1978. Later refinements produced a world class product that was adopted by maritime shipping and also used for evaluating industrial boilers in North America.

The investigation of the cracking of the foils of the FHE-400 hydrofoil showed that the problem was due to a combination of stress corrosion and hydrogen embrittlement of the Maraging 250 steel used in their construction. This stimulated the initiation of a program at DREP on the new science of fracture mechanics. Extensive work was subsequently undertaken on the fatigue resistance, temper embrittlement, stress corrosion cracking resistance and hydrogen cracking resistance of a replacement material, HY 130 steel. It was concluded, in 1977, that this steel, even in a welded condition, was resistant to the failure mechanisms that plagued the Maraging steel.

In 1976, Dr J.R. (Jim) Matthews, who had recently transferred from DREV to DREP, began to address the problem of the loss of a number of the Navy's AN/SQS 505 variable depth sonar bodies due to breakage of their towing cables. The breaks usually occurred at or near the connection to the towed body—some time earlier, Jack Carson had observed that they were due to corrosion of the cable and had devised methods to alleviate the problem. Jim Matthews and his associates developed and implemented techniques, based on acoustic emission and radiography, for detecting potential and actual failure of the strands of the tow cable and for detecting shorts in the cable wiring respectively. A method was also developed for reterminating cables at sea, thus further reducing downtime in operational situations. These developments combined reduced significantly the substantial operational and financial penalties associated with the loss of a towed sonar body.

In 1975, a survey of Canadian activity in engine health monitoring (EHM) was undertaken by Clint Waggoner to assess the merits of participation in a proposed TTCP research program to study failure mechanisms and develop improved diagnostic sensors. As considerable interest was shown by DND, NRC, some universities and commercial airlines, DREP joined the US and UK in a co-operative program relating to failure mechanisms and to sensor development based on wear-particle and lubricant assessment. A year later, experimental work was begun on a collaborative research program on 'Failure Mechanisms in Lubricated Systems' with particular reference to gas turbine and helicopter gearing machinery.

Throughout the period, interactions with the Air Force steadily increased. These included spectrographic analysis of contaminants in aircraft engine lubricants and hydraulic fluids, radiography of structural members of aircraft flaps, wheels and other components, exploration of metallurgical effects of a lightning strike, and analysis of the rupturing of alloy bolts on an aircraft exhaust casing and fatigue cracks in helicopter rotor blades. A shock pulse meter for detecting faulty bearings in helicopter transmissions was also evaluated. As a result of a recommendation of the Materials Technology Review Committee,[40] activities were initiated at DREP in fibre composite materials and augmented in welding science and nondestructive evaluation. The work in composites was related to the greatly increased importance of advanced fibre composites in military equipment, particularly the CF-18 fighter aircraft which contained approximately 10% by weight of graphite-epoxy composite distributed over about 40% of its exposed surface. A Composites Group was set up under Dr K.N. (Ken) Street, who had recently joined DREP having already achieved recognition for his work in composite materials in England at the National Physical Laboratory and in France at the École des Mines de Paris. The composites work was initially concentrated on in-house fabrication facilities for the production of laboratory-scale organic-matrix composite materials and on studies of the environmental degradation of typical advanced fibre materials. Mr W.R. (Bill) Sturrock, an engineer with extensive experience in aircraft structures—acquired from his previous employment with Boeing and Northrop—joined the Metallurgy and NDE Group and concentrated his work on the identification of flaws and the improvement of flaw detection and measurement techniques in composite materials and their joints. Later, this expertise was also applied to

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[40] The Committee, composed of representatives from NDHQ, DREO, DREV and DREP (Frank Peters), met in 1976-1977 to examine the state of materials research in Canada and to assess its ability to respond to the needs of the Canadian Forces in development, maintenance and operations. The augmentation of the materials program at DREP followed from the recommendations of the Committee.

Building 204, the centre for air materials related research

metallic structures in aircraft. Because of the impossibility of acquiring a staff large enough to carry out all the work in-house, extensive use was made of contracts in both industry and universities.[41]

The Laboratory was also receptive to working on army related problems: machine gun barrel extension cracking (1974); properties of steel for armoured vehicles (1976); and adhesion of paint on portable bridges (1977). A number of attempts were made to increase this level of activity, with some success; however, only rarely did this involve more than 10% of the Materials Engineering effort.

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In September 1978 Dr Flynn retired and was replaced by Mr R.A. (Dick) Kendall.

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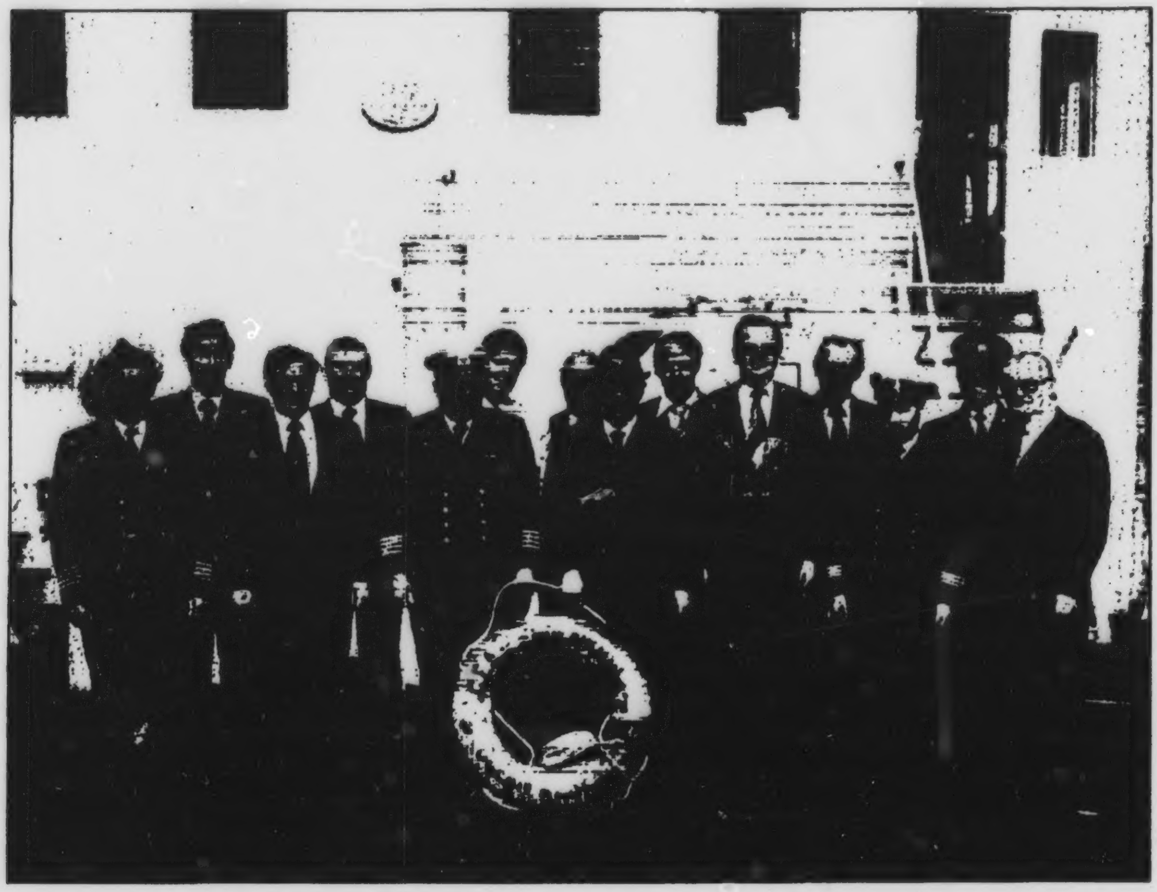
[41] Contracting had been a prominent feature of the materials program since 1974 when the DRB University Grants Committee, the main source of DRB funding for research at universities, was cancelled. Motivated by an increased commitment to co-operative research in materials in TTCP Subgroup P, DREP decided to support, with research contracts, those university activities in materials science that had the most defence relevance. This was quickly followed by contracts to industry in chemistry, metallurgy, paints and corrosion.

1979 to 1980 - Interest develops in mine countermeasures and Arctic Basin surveillance

Organization, facilities and trends

Dick Kendall was initially employed as a scientist at SES, and followed Jim Flynn as the leader of the nuclear weapons trials party in Australia. Later, he was posted to the UK Atomic Weapons Research Establishment (AWRE) at Aldermaston. Shortly after his return to Suffield, he transferred to the underwater acoustics program at DREA, rising through the various levels of responsibility to become the Director of the Underwater Acoustics Division. During his tenure as Chief of DREP, a number of changes to the program and organization were implemented; the buildup of the materials program in composites and NDE continued; and a number of initiatives were taken which would later result in a substantial program in mine countermeasures. Associated with these activities was an increased level of involvement with TTCP.



Mr Kendall takes CRAD Chiefs on a tour of ENDEAVOUR. (front row) Chief Engineer D. Dougherty, Dr J.B. Reesor (D/CRAD[P]), Captain E. Jensen, Mr E.J. Bobyn (CRAD), Mr R.A. Kendall (C/DREP), First Mate A. Fraser, Mr B. Baker (D/CRAD[D]); (back row) Dr W.G. Brownlee (C/DREV), Mr F.A.A. Fergusson (C/DREA), Col R. Fassold (A/C/DCIEM), Dr R.M. Heggie (C/DRES), Mr C.R. Iverson (C/DREO), Dr D. Schofield (D/CRAD[L]), Maj K. Garland (SO/CRAD)

To cater to the increased responsibilities, the staff continued its modest growth, reaching 136 civilian and 3 military positions in 1980. This was accomplished in spite of the most difficult recruiting conditions in decades. The economy was booming and there was very severe competition from industry, even reflected in the hiring of co-op students—usually in good supply—who found government wages uncompetitive with those in the then thriving oil industry. The problem was further exacerbated by an explosion in housing prices which made it impossible for most recent graduates to consider moving to Victoria.

DREP/PNL, almost from its inception, had assumed responsibility for research in mine countermeasures. Generally the level of activity was low, more or less faithfully reflecting the level of CF interest in the subject. However, during the preceding two years, interest had perked up, with NDHQ military and operations research staff carrying out a study of future requirements and recommending significantly increased involvement in this activity. In the late 1970s, John Smith,[42] as an observer at meetings of TTCP GTP-13, the Mine Countermeasures Panel, had kept a watching brief on MCM research activities in allied countries. In an effort to become more heavily involved, Canada assumed, in 1979, full membership in the Panel, with Erwin Lokken as National Leader. This placed DREP in an excellent position to avail itself of the experience in other countries and to devise an MCM research program which would both complement those in the other countries and be responsive to the needs of the CF.

In the late 1970's and early 1980's, DREP's influence in the Air Element steadily increased. This was reflected in the hosting of a number of well attended symposia—two in NDE and one in Composites—for the growing Air Force materials community. By this time, as the military had already created its own NDE Development Unit in Trenton, DREP's NDE work in support of the CF became concentrated exclusively on research.

Ocean Acoustics

By this time, the underwater field-trials program in the Pacific had settled down to approximately three field trials per year: one, with MEVA, devoted to sound propagation and ambient noise; a second, with the towed arrays, making measurements of flow and ambient noise, and other factors affecting detection performance; and, the third, which involved co-manning the towed array installation on ENDEAVOUR with MARPAC in a variety of military training and operational exercises. In 1979, this provided the opportunity to exercise with US and UK nuclear submarines and an Australian O-boat.

Although towed arrays are relatively trouble free in operation—an exception being at the lower latitudes where they are subject to attack by sharks—other problems can arise, and did. In mid-1979, the 10-ton winch and array made an impressive hole in ENDEAVOUR's quarterdeck. Later in the same year, the cable and array spooled itself off into several thousand metres of water. Fortunately, no one was injured in either episode, the problems and procedures responsible rectified, and the array quickly replaced.

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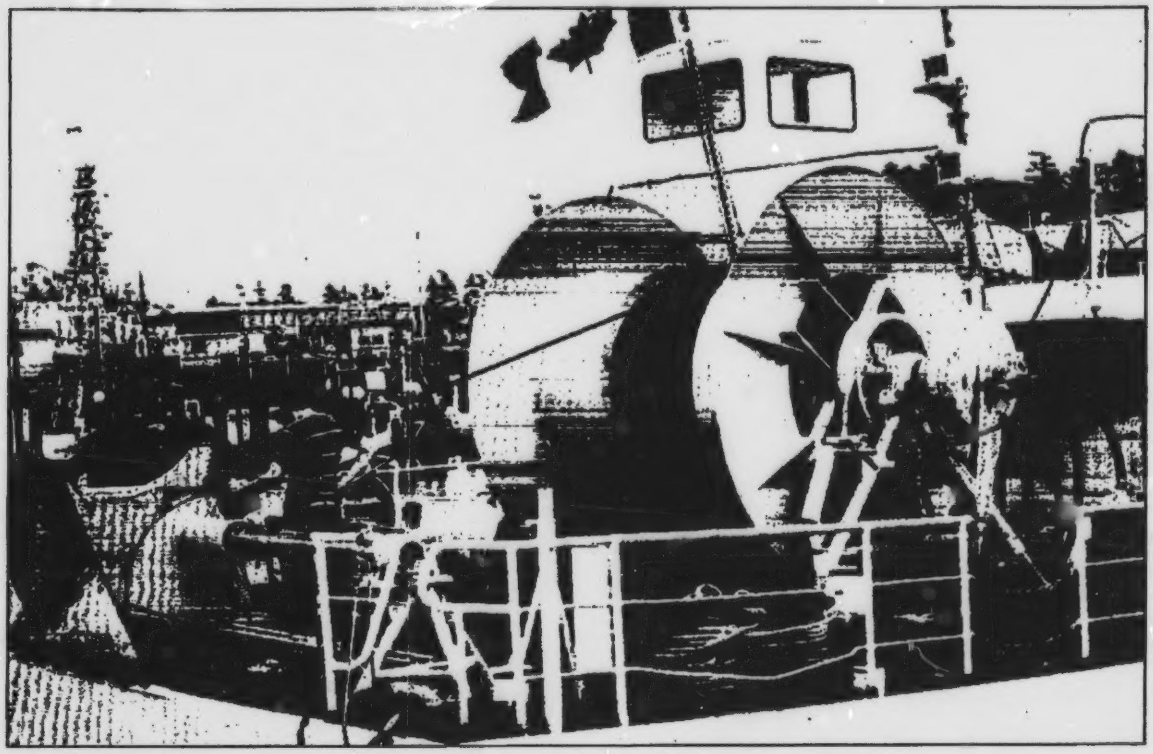
[42] While a member of the Washington Liaison Staff from November 1976 to August 1979.

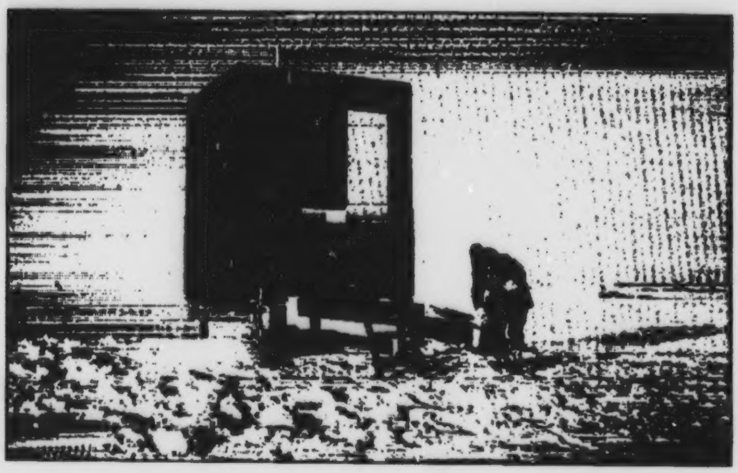


COAMS towed array installation on ENDEAVOUR being inspected by Bruce Dunwoody

Arctic Acoustics

The 1978-study on surveillance in the channels was based primarily on what happens under water; the problems of data transmission, processing, display, and analysis at a remote location had yet to be addressed. As Computing Devices of Canada had achieved considerable expertise in this area—through their work on the US SOSUS system—it was selected to look after these aspects of the problem, under a series of contracts extending over the next five years. A considerable amount of experimental activity continued in the channels to address issues brought up in the original study or the Computing Devices investigations, or to address other problems relating to surveillance. In 1979, ambient noise, sound propagation and array performance measurements were made at Mould Bay in M'Clure Strait at the west end of Parry Channel. The trial extended out into the Arctic Basin, initiating a renewed interest in basin surveillance. The following year an icecamp with a suspended receiving array was set up on an ice-plug at the mouth of Nansen Sound to conduct a follow-on experiment related to basin surveillance.

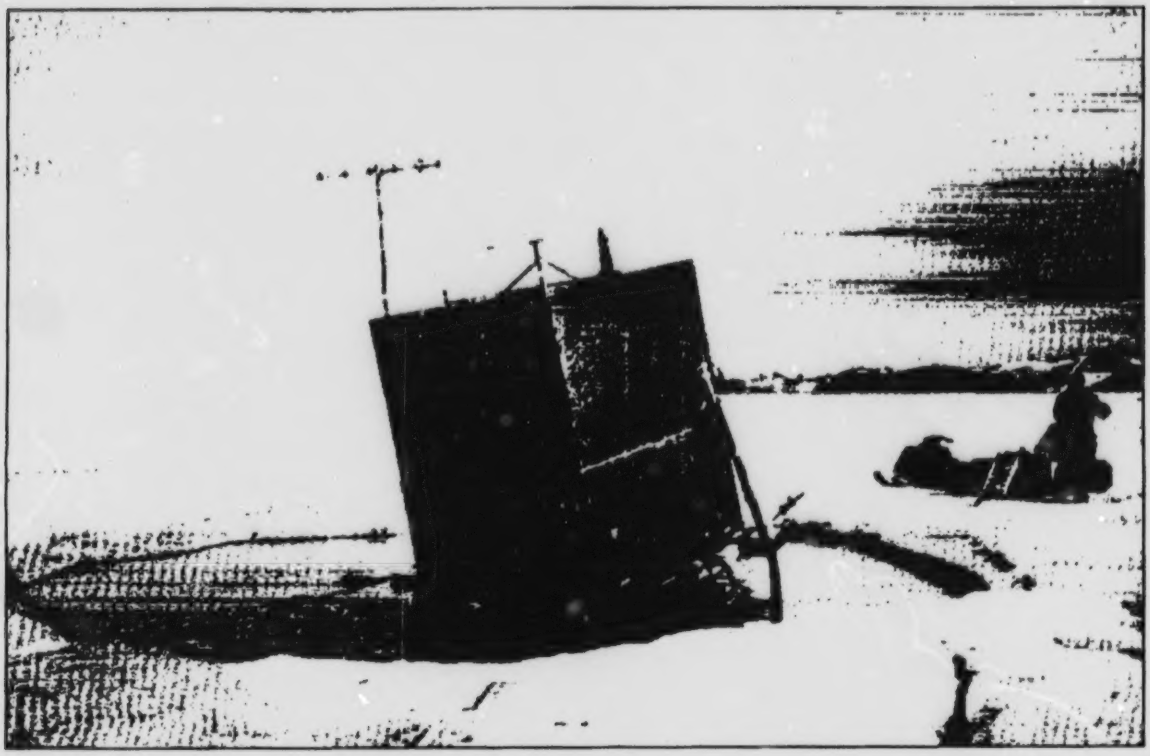
Ice-plugs (~10 metres thick) and ice-shelves (up to 50 metres thick) are semi-permanent features, prominent on the northeast coast of the Arctic Archipelago, which may remain in place for decades. As such they are extremely attractive platforms for making underwater acoustic measurements. They neatly avoid the problem of the destruction of cables by ice movement at the shoreline and, by their stability, facilitate the measurement of long time-series. However, they do present some very interesting technical problems. For example, on an ice-shelf, approximately one metre of ice disappears from the ice surface each



Installation: ice-hut on adjustable stilts

Ablation: a year later the building is ready to be lowered on its stilts

year due to solar ablation, but, as a similar amount grows on the bottom surface, the ice thickness remains essentially unchanged. This has the interesting effect of causing a structure left on the ice to rise on an ice pinnacle at approximately one metre per year, eventually to fall over. The solution to the problem is to mount the building on stilts; from time to time, it is lowered on the stilts both to ease access and maintain stability. Another problem is that of installing hydrophones through the thick ice. To do this, Dr R.I. (Ron) Verrall and Mr D.G. (Dave) Baade developed a hot water ice-drill capable of drilling through even the thickest ice. If the sensor is connected to an armoured cable, it can also be readily recovered using the ice-drill. Conductivity ensures that the drill follows the cable, no matter how thick the ice. Other problems are more pedestrian, but no less important. Extreme cold exists in these regions—down to -60°C—which both causes heating fuel to solidify and welds in stoves to crack. When the fuel heats up and becomes liquid a serious fire may occur. This in fact happened at one of our camps in 1980 and again a few years later. These events reinforced the Arctic adage; have a second tent filled with survival gear near-by, but not so close that it will get caught up in the conflagration. This highlights one of the principal concerns with drastic downsizing of programs; the experience and technical and survival skills acquired over decades may become lost in the shuffle, to the serious detriment of future operations.



Desolation: on a later occasion the elements conspired to cause practice to depart from theory - it was however a useful learning experience

Fluid Dynamics

Blyth Hughes had concluded that an airborne nadir-looking infra-red scatterometer would be an effective tool for carrying out research on variations in sea surface roughness and at considerably less cost than with a synthetic aperture radar. Accordingly, he set out to contract with industry to build two scatterometers which could be flown on small aircraft. The first, to be constructed as an interim measure, would contain a single spot aimed directly down at the sea surface and as such would provide roughness statistics. This contract went to OPTECH INC. The second, which would scan back and forth at right angles to the aircraft's track, would be suitable for detecting internal wave patterns. It was contracted to SPAR AEROSPACE. Both were satisfactorily completed and used in experiments in the early 1980s.

Electromagnetics

From June 1979 to June 1980, an airborne MAD system, based on the DREP detection algorithm, a commercial mini-computer and the prototype CAE ASQ-502 optically pumped caesium vapour magnetometer, was flown and tested on the MP&EU Argus aircraft. The results were encouraging, so it was decided to implement the algorithm on a much smaller microprocessor system for further airborne trials and evaluation.

The contract for the construction of a multicomponent—originally specified as five but later changed to six to include a redundant channel—gradiometer was let to CTF. Construction was completed in 1980, followed by stationary tests at a low-gradient test facility constructed at the end of the runway of the Pitt Meadows Airport. Because of all the activity in the area, the site, although satisfactory, was far from ideal. Hence, a search was initiated for a more satisfactory location, hopefully much closer to the laboratory.

Investigations of the effect of the shoreline on micropulsations continued, in co-operation with UVic. Field trials were conducted at Assistance Bay in both 1979 and 1980 using lines of sensors on the ice extending out from the shore. The experiments were designed to assess the effect of the discontinuity at the land-sea interface at frequencies relevant to barrier arrays, MAD and mines. The results were compared with those predicted based on a model developed at the University. These investigations formed the basis for a PhD thesis by Dr G.J. (Garry) Heard who, following graduation, was employed first at DREA and then at DREP.

Materials

The emphasis was placed on advanced composite materials, fracture mechanics, nondestructive evaluation, welding technology, paints and corrosion, and engine health monitoring. The development of programs in composites and nondestructive evaluation continued in anticipation of the arrival of the new high performance aircraft, the CF-18.

Research using a thin film electron microscope led Frank Peters to develop a theory explaining the textures formed in alloys such as brasses and bronzes during recrystallization. His sequential twinning model aids in the understanding of the effects of cold working and heat treatment on useful material properties such as strength, toughness and resistance to cracking. His work stimulated additional research at several materials research centres, including the development of computer programs which confirmed the model, thereby ensuring its place in the literature as an accepted mechanism.[43]

The responsibility for coatings research was assumed by Dr T. (Terry) Foster, who returned to the Laboratory in 1979 after completing his doctoral studies. Jack Carson retired in 1980 and was replaced as Group Leader of the DREP Corrosion and Paints Group by Dr D. (Derek) Lenard, an electrochemist who up to that time had been in charge of the ship corrosion work at DREA.

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Dick Kendall retired in December 1980 and was replaced as Chief by Harold Grant.

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[43] Over the years, many other members of the Materials Technology Section also became well recognized experts in their fields. Jack Carson's work on marine corrosion established him as Canada's leading expert in this subject. His paper, *Principles of Design of Cathodic Protection Systems for the Hulls of Active Ships*, was adopted by the National Association of Corrosion Engineers (NACE) as the classic reference for the design of cathodic protection systems for ships. Ralph Barer and Frank Peters' textbook on metal fatigue failure analysis, *Why Metals Fail*, was also recognized by a number of international organizations as a definitive reference. It was also used as a textbook in a metallurgical course at Queens. Ken Street and Alan Russel's work on composite science was also well recognized in TTCP and in the aircraft industry. Similar recognition was afforded to Clint Waggoner and Terry Foster for their work on engine health monitoring and aircraft paint removal respectively.

1981 to 1985 - final experiments in fluid dynamics - increased activity in air related projects

Organization, facilities and trends

Harold Grant's promotion created a vacancy which flowed downward through the organization resulting in Bob Chapman and Ashton Patterson becoming Director of Physics Research and Head of Ocean Physics respectively. In February 1984, John Smith, after serving three years in Ocean Acoustics, reassumed his position as Head of Applied Technology; Ashton Patterson was appointed Head of Plans and Programs; Glenn Turner was made Head of Ocean Physics and Jim Kennedy became Group Leader of Ocean Acoustics. Later in the same year, mine countermeasures had developed to the point where it became recognized both as a separate project and group, with Ron Kuwahara as Group Leader.

In 1982, Frank Peters became the Head of the Dockyard Laboratory at DREA. He was replaced at DREP by Dr J. (Jack) Morrison, an expert in fracture and metal fatigue, who transferred from DREV to take over the leadership of the Metallurgy and Nondestructive Evaluation Group. He expanded the laboratory's capabilities by initiating work in the fracture mechanics of marine steels. The Group was later subdivided with Bill Sturrock taking over NDE.

Dr Grant welcomes the Minister of National Defence, Jean-Jacques Blais, to DREP

By 1981, the growth in staff which had been fairly steady over the preceding thirty-odd years had now ceased. Vacancies could, however, be filled, and recruiting was no longer a problem. Due to a severe recession in 1981 and 1982, industry found itself, in a number of cases, unable to honour offers to recent graduates, thus throwing a number of excellent prospects back on the market. In addition, in mid-1983, housing prices in Victoria collapsed. The combination of these events made employment at DREP very attractive, thus permitting the recruitment of a number of outstanding candidates.

The overcrowding problem generated in previous years now began to be addressed with a series of additions to the back of Building 199. The first, a "Fluid Dynamics" extension on the third floor, was completed in December 1984. Shortly after, planning began for another third floor addition, this time a classified computing facility.

Ocean Acoustics

During this period, emphasis was placed on the development of techniques for passive ranging of submarines and for geoacoustic modelling of the ocean bottom. In these activities, significant support was obtained from industry and the local military college. A modest effort was also applied to active ranging of submarines using the towed array as receiver. There was

Mr Bobyn and Glenn Turner discuss the mechanical aspects of towed array design

an increased involvement in system studies in support of CF acquisition projects. Co-operation with MARPAC in military exercises continued, for the tenth consecutive year.

Shortly after the arrival of the first towed array, DREP staff developed an interest in passive ranging, an activity designed to assist maritime air units in their efforts to localize targets detected by ship-deployed arrays. Initially, the investigations concentrated on multi-path ranging using CW-signals. The method consisted of measuring the vertical angle of arrival of the direct and bottom reflected arrivals, and then, knowing the water depth, working out a range by simple trigonometry. The method works particularly well over flat smooth ocean bottoms, not an uncommon condition in the numerous abyssal plains found in the MARPAC area. As the beam patterns of towed arrays consist of concentric cones about the array axis the method works best at or near end-fire and not at all at broadside. By 1983, further investigations of this technique were being carried out under contract with Computing Devices of Canada to evaluate its applicability to CANTASS. DREP, meanwhile, had started research on a complementary technique using broad-band emissions. Through correlation techniques, time delays between the various multi-path arrivals are computed, again facilitating a geometric solution. This process works best at broadside. A year later, investigations began of a number of Target Motion Analysis (TMA) techniques which employed bearings-only and bearings-plus-doppler methods. While they require tow-ship manoeuvres and relatively long holding times, they can provide accurate range estimates in those situations where multi-path signals are not present.

The development of the towed arrays and MEVA into successful operating systems owed much to the initiatives and outstanding technical capabilities of Bob Chappell

By this time, it had become evident that the ideal solution to the passive ranging problem would be a suite of techniques which could be used either singly or in combination depending on circumstances. Matched field processing (MFP)—then being introduced to DREP by Arctic Acoustics—and space-time integration (STI) would later be included to complete the suite.

As an active adjunct to a towed array is another possibility for determining target range, it was decided to also investigate this technique. Explosives were once again selected as sound sources as they were powerful, inexpensive and wide-band, all desirable characteristics for experimental acoustic studies where high repetition rates over long periods are not required. The first trial, using COAMS II and both line and omnidirectional charges, took place in June 1982. Measurements were made of the continuous reverberation background and of the sound scattered by distinct features such as seamounts. The initial measurements were conducted by Jim Kennedy. The program was later turned over to Mr D.R. (Dennis) Haller, who successfully modelled the experimental results. The investigation was terminated on his departure in 1989.

The exploitation of bottom reflected propagation paths, such as those used in passive ranging, requires a good knowledge of the interaction of low-frequency sound with the ocean bottom. At this time, approximately one field trial per year—using MEVA as the receiver and either explosives or towed CW-projectors as sound sources—was devoted to the investigation of this phenomenon. By 1982, Ross Chapman had developed geoacoustic models of the bottom for sites on both the Tufts and Alaskan Abyssal Plains. The analytic techniques and software used in these investigations to extract the impulse response of the bottom were produced through a research contract with Barrodale Computing Services (BCS). The techniques were sufficiently in advance of those then used in seismic surveys by the oil industry that they resulted in a sale to a major international oil company. The contractor also adapted these techniques to DREP's ultrasonic investigations of defects in aircraft structures. Again a foreign sale resulted, this time to a major aircraft manufacturer. This was a rather good example of technology transfer, both to industry and across the playing field. It parallels that of the development of shaft grounding in Materials Engineering and its extensive use in MCM. These transfers demonstrate the surprising degree of synergism that can exist between programs that on the face of it are quite disparate.

Following the earlier work in the TACTASS Study, development continued on a towed array sonar simulation capability. This facilitated the Laboratory's participation in a number of systems studies carried out by CRAD in support of CF development and acquisition projects. In 1981 and 1982, DREP participated in the DREA-led Helicopter Acoustic Sensor System (HASS) Study, by providing predictions of the size of the search area resulting from towed array detections, and estimates of helicopter MAD performance. In 1983 and 1984, it contributed to the Submarine Sonar Systems (3S) Study both through the management of the study and by determining the performance achievable with a number of candidate arrays towed by a modern diesel-electric submarine. These studies benefitted immensely from the broad capability being built up in the laboratory in low-frequency sound propagation modelling; by this time, a number of USN models had been included in the facility and a range-dependent wide-angle Parabolic Equation (PE) model had been developed in-house. Also, through DREP-sponsored research at RRMC and Barrodale Computing Services, a noise field simulation model was developed and used to investigate the performance of the advanced beamforming techniques assumed in the studies.

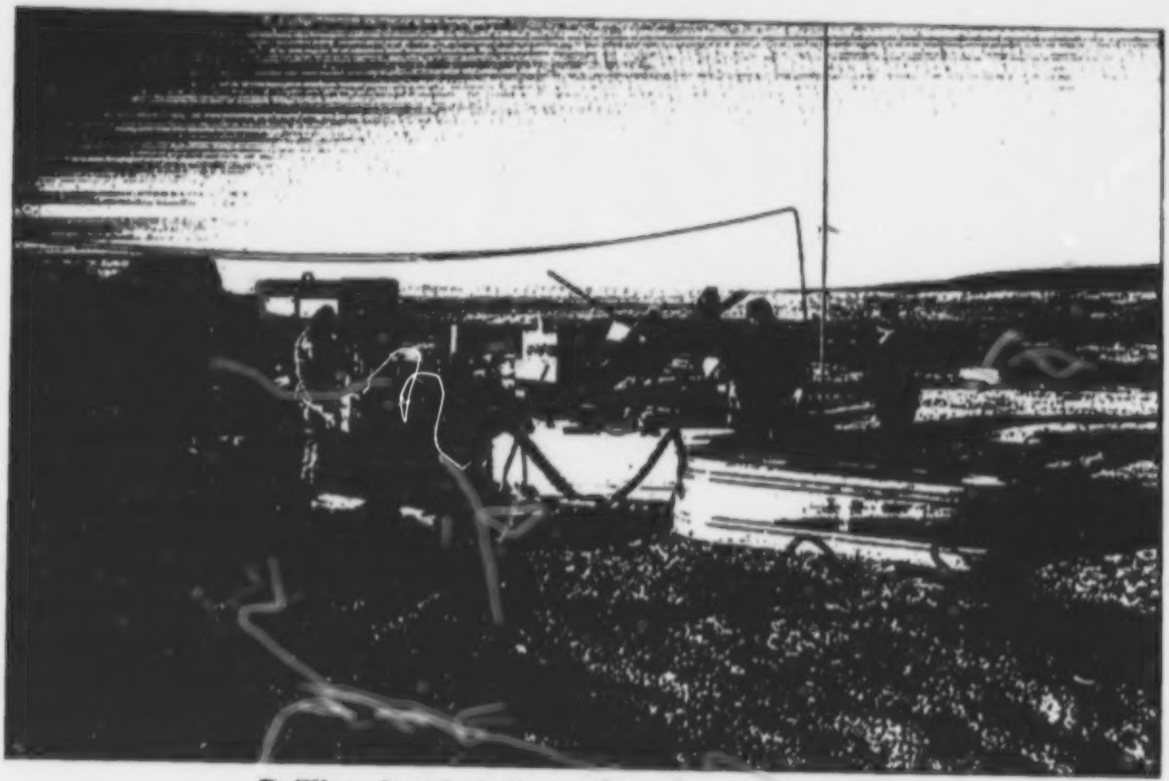
Arctic Acoustics

Attention was still being given to research in the channels of the Archipelago but, more and more, emphasis was being placed on investigations of the acoustic environment at various locations on the north coast of Ellesmere Island.

In September 1981, an array of hydrophones was placed on the bottom in Jones Sound and connected to recording facilities in a small building at Grise Fiord. Measurements were then made of sound propagation to the hydrophones under open-water conditions. The following April, the measurements were repeated under ice-cover. Ambient noise was recorded continuously from the time that the hydrophones were installed until the cables were severed during ice breakup later in the year. The damage was repaired in 1983 with the assistance of the Canadian Coast Guard icebreaker SIR JOHN A MACDONALD.

Taking advantage of the availability of the icebreaker, cables were also repaired at Gascoyne Inlet and batteries replaced at the shore station and telemetry sites. Although, through the co-operation of the Coast Guard and MARCOM, enough ships and divers were available to permit the essentially annual repair of cables, the situation was clearly unsatisfactory. Time-series of noise backgrounds were undesirably truncated, and the repairs were a continuing drain on DREP resources, resources which could better be employed elsewhere. Additionally, significant breaks in information would clearly be unacceptable in operational systems. Thus it was decided to investigate a brute force solution; drill through the beach and enter the water at a depth below that at which ice was likely to occur. Fortunately for DREP, but unfortunately for the oil drilling industry, a long-term world-wide hiatus in oil exploration was then in progress—between 1981 and 1985, the Alberta oil industry had laid off 50,000 people. Thus it appeared that the costs of drilling might have dropped to the point where they were affordable by a research program. And so it turned out; when word got around Calgary that there was a customer who could seriously discuss a contract in the neighborhood of $100,000, pandemonium broke loose and even resulted in a Ministerial Inquiry to ensure that all those who previously thought in terms of millions and billions had a fair chance for the contract. An oil drilling rig and crew were flown to Resolute Bay in August 1985 and transported by twin-Otter to Gascoyne where the desired slant-hole was drilled through the beach. The operations, supervised by Dave Baade, was an unqualified success; years later the cable deployed through the hole had yet to suffer any damage. It later appeared that the gravel beach found at this location was unusually satisfactory for drilling. At other sites where the exit had to be made through extensive deposits of glacial till, drilling was much more difficult. It was still the right thing to do, although at costs more recognizable to traditionalists in the oil industry.

The program to measure propagation loss in the various channels was accompanied by a substantial modelling effort, both to interpret the experimental results and to develop a predictive capability for other situations and locations. This required relatively sophisticated models which included the effects of shear and viscous absorption in solid layered bottoms and of small scale roughness of the sea floor. This effort was largely the responsibility of Dr G.H. (Gary) Brooke who made ancillary measurements of the geophysical parameters required, adopted relevant models from other agencies—particularly SACLANTCEN—and saw to the development of additional models either on his own or under contract. The contracting included scale model experiments in which the various acoustic parameters could be varied individually thus permitting an evaluation of their relative importance. This work—conducted by SONOQUEST, a US firm—was initially funded by DREP. However, it soon caught the attention of the USN Office of Navy Research (ONR) who became a co-sponsor.



Drilling slant-hole through the beach at Gascoyne

At this time, advanced signal processing also became a prominent feature of the Arctic research program. Initially, it was devoted to high resolution techniques for distinguishing between closely spaced targets or determining target depth. Later, driven by the enthusiasm of Dr J.M. (John) Ozard, it tackled matched field processing (MFP), a technique where effectively the amplitude and phase of signals received at every hydrophone of an array are compared with those computed for a target at every point in the ocean, based on acoustic modelling. The best match provides the estimated range, depth and bearing of the target. The process requires accurate propagation modelling, a capability whose development was well under way. It is also very computing intensive. Thus with the rapid developments in computing power that were then in progress, the process became more and more realistic. Even so, the demands on computers were such that if the process was to be carried out in real time, it would still be necessary to develop strategies and techniques to cope. MFP later became central to work on underwater acoustics in the Arctic and also formed an important component of that in the Pacific as well.

The initial trial to demonstrate feasibility of MFP was conducted in 1984 in the shallow water approaches to Esquimalt Harbour. The location was chosen to eliminate the logistics problem associated with working in the Arctic and to maximize the control over the experiment. Although the demonstration was a success, it was not, however, without incident. While John Smith was installing the five hydrophones of the array and connecting them to a shore site, he was closely watched by fishermen operating in the area. Sure enough, the next morning a fisherman arrived at MARPAC headquarters with a hydrophone in hand to claim his reward for finding lost Navy equipment. It was patiently explained to him that, under the circumstances, there was to be no reward and that it would be better for all concerned if the other four hydrophones remained untouched. Although the harvest of hydrophones continued, no reward was ever paid, hydrophones proving to be an even less reliable cash crop than cod or turbot.

As the channels became sufficiently well studied, effort was redeployed to the Arctic Basin to investigate the acoustics at the semi-permanent ice features along the north shore of Ellesmere Island. In 1981, the ice plug at Nansen Sound was revisited, uneventfully except for a wolf eating the anemometer at the icecamp. Over the years DREP staff had become fairly adept at dealing with polar bears—a necessity seeing that the camp at Gascoyne was situated in a denning ground—without damage to either party. Wolves were something else. Being territorial, they regarded anything brought into their territory as theirs. What they could eat, they did; what they could move, they carted off; anything else, they marked. Unlike adapting to bears, there was a casualty, although the case has been made that the unfortunate animal committed suicide.

Sound propagation measurements were carried out from Nansen Sound in co-operation with a team of scientists from NRL. This trial also afforded the first opportunity for testing the hot water ice drill. The tests were conducted on a glacier near the mouth of the Sound. Results were encouraging in that the drill easily penetrated the 21-metre thickness of the glacier. A year later, an experiment was conducted from the Ward Hunt Ice Shelf to measure sound propagation and ambient noise. The hot-water drill proved equal to the task of penetrating the 50-metre thickness of the shelf—as severe a test as any likely to be encountered anywhere in the Arctic Basin—and a single hydrophone was deployed. Although otherwise an excellent platform for conducting long-term experiments, the iceshelf contained a serious defect, in that sound propagation conditions, due presumably to a combination of shoaling and extremely rough ice seaward of the shelf, were far from ideal. The search for a more satisfactory site continued.

In April 1983, propagation trials were carried out using hydrophones suspended from the 6-metre and 9-metre ice plugs at Yelverton Bay and Milne Fiord respectively. The results were encouraging, so remote low-power data acquisition systems were installed at both locations to transmit averaged ambient noise levels back to DREP on a continuous, long-term basis via the ARGOS satellite system, thus fulfilling the dream of many an Arctic researcher of conducting research in the Arctic without having to leave the office in Victoria.

In August, sound propagation trials were again conducted in co-operation with the US using the hydrophone installations at both Yelverton Bay and Nansen Sound. In the ensuing years the already extensive co-operation with the USN, their laboratories and scientists continued to grow, eventually involving several laboratories, and field trials parties of more than 60 scientists and technical support staff.

A major field trial was conducted at Yelverton in May 1984 to extend the range of sound propagation and to determine array gains for both horizontal and vertical arrays. Unfortunately, a follow-on experiment to measure the signal coherence for a 2-km horizontal array had to be cancelled, the hydrophone installation and icecamp having been destroyed when the ice broke away in June. As these ice plugs are semi-permanent and break up every 30 to 40 years or so, such losses are inevitable and part of the cost of conducting operations in this hostile environment. The next year, an air search located the missing icecamp. The surviving components which were small enough to be lifted by helicopter were recovered. This did, however, mark the end of activities at Yelverton.

Fluid Dynamics

In 1981 and 1982, the Fluid Dynamics Group was involved in a program to measure speckle associated with remote sensing of the ocean surface using near-IR scatterometers. The measurements were made with the OPTECH gyro-stabilized, single-spot, vertical-beam scatterometer. Initial tests employing a helicopter as a measurement platform proved to be inconclusive due to excessive vibration and exhaust smoke blown into the field of view of the scatterometer by the rotors. Thus in 1982, the helicopter was abandoned, and measurements made, initially from the Lion's Gate Bridge spanning Vancouver Harbour and later from a small fixed-wing aircraft.

Next the Group took part in the Joint CAN/US Ocean Wave Investigation Project (JOWIP) whose central objective was to image, with SAR and IR-scatterometry, ship wakes, surface ship produced internal waves, and natural internal waves. The experiment took place in Georgia Strait in July/August 1983 in cooperation with several US laboratories. It was one of the first operations to use IR-imaging from the SEASAT satellite. Data for comparison were collected using the SPAR AEROSPACE scanning near-IR scatterometer flown in the NAE Convair 580.

In August/September of the following year an experiment was conducted in the New York Bight off Long Island to supplement the natural internal wave portion of JOWIP. This experiment, called the Synthetic Aperture Radar Signature Experiment (SARSEX), was again carried out in co-operation with a number of US laboratories. The scanning scatterometer was flown on six days, quite successfully, as internal waves were clearly imaged on twelve passes made simultaneous and coincident with SAR images.

The results of the JOWIP and SARSEX were published in a special issue of the Journal of Geophysical Research. There was substantial agreement between the experimental results and the theories developed over the years at DREP by Blyth Hughes. This essentially concluded the research which could usefully be done without a very substantial outlay for new equipment; the next logical step was considered to require an as-yet-unbuilt state-of-the-art radar, an acquisition well exceeding both the resources and technical expertise available at DREP. Thus, in 1987, the project was terminated and the Group redeployed to supply theoretical support to underwater acoustics in the Arctic. DREO, being heavily into radar, had been an interested follower of the work on sea surface patterns and retained its interest in the subject. It was therefore agreed that it would assume responsibility for any further research or international co-operation in this area.

Electromagnetics

DREP's microprocessor-based MAD detection system underwent further trials on both fixed-wing aircraft and helicopters. In 1981, this unit was evaluated on one of the recently-purchased Canadian Forces Aurora aircraft during an exercise over an Oberon class submarine and a medium size fishing vessel, both located on the Scotian Shelf. The performance was comparable to that of an experienced operator, except that the machine made decisions more quickly. The processor, in association with a CAE MAD system, was also successfully tested on a US helicopter at the Naval Air Test Center in Rhode Island. At this time, the CF was giving some thought to replacing their Sea King helicopters, and hence became interested in obtaining a prototype inboard MAD system for evaluation and possible use in the new helicopter. As a result of these activities, CAE decided to merge their optically pumped magnetometer and aircraft compensation system with the DREP signal processor to form the Automatic Integrated Magnetic Anomaly Detection System (AIMS) for both fixed-wing aircraft and helicopter use. In 1983, Keith Yeung, a DREP engineer heavily involved in the design and field testing of the processor, spent June and July at CAE assisting in the initial transfer of the algorithm. Following this, contact was maintained to further refine the system and to participate in helicopter trials in both Canada and the UK. The CF then purchased an AIMS unit for evaluation in a Sea King helicopter and DREP was tasked to provide advice and technical support. In September 1984, the Helicopter Operational Test and Evaluation Facility (HOTEF), in conjunction with CAE and DREP, conducted a magnetic survey of a Sea King at Shearwater. The purpose was to determine the most suitable location for the AIMS detector in order that further engineering on a retractable or removable boom or pod could be accomplished. The results of the survey were encouraging in that it appeared that an internal tail-mounted detector was feasible and offered numerous advantages over any other position. These included light weight, mechanical rigidity, no boom, lack of aerodynamic restrictions, and other advantages related to weapons drop and the requirement for electromagnetic shielding. The internal location was at that time unique to any helicopter MAD system. Others used magnetometers in towed birds, a considerably more complicated way of operating.

The first feasibility flights were conducted by HOTEF in February and March 1985 using a temporary installation of the AIMS. These trials indicated that the tail-mounted anti-collision light, because of its ground return path, produced a magnetic field so intense that MAD was unusable, and the powerful magnetic field of the search radar moving within its shock mounts seriously degraded the systems figure-of-merit and introduced a random modulation of the background field. It was concluded that these problems could be eliminated by rewiring and shielding, modifications which were made to a helicopter at Shearwater in September 1985. The modifications to the radar were developed at DREP, based on field cancellation by a magnet placed beside the radar but with polarity opposite to that of its magnetron. Trials conducted later in the fall indicated both substantial improvement and the desirability of making further changes to the magnetic state of the aircraft. Trials of the AIMS took place in the UK in December 1984 and January 1985 with Roy Erickson heavily involved. He participated in a mid-trial redesign of both the hardware and the signal processing and compensation software to produce a working system for a test with a LYNX helicopter. Having demonstrated the feasibility of in-board helicopter MAD to both the Canadians and British, additional trials were then conducted in the US with DREP staff participating in the analysis of the data.

Keith Leung conducting MAD trials

For some time the CF, NAE, CAE and DREP had been interested in the compensation of aircraft for motion-induced electromagnetic noise. With the development of a more sensitive MAD system for the Auroras and the possibility of installing a similar system on the Sea Kings or their replacements, interest intensified. Accordingly, DREP contracted BCS to develop a computer simulation of a magnetically uncompensated aircraft, primarily for evaluating compensation algorithms for the Aurora. Brad Nelson took responsibility for the evaluation and ultimately developed compensation manoeuvres which not only were more effective than those used earlier but which involved much less violent manoeuvring of the aircraft. The latter was particularly appreciated by the aircrews who no longer had to associate adequate aircraft compensation with airsickness.

MADSIM was converted by BCS to a user-friendly program for the MP&EU computer. It was installed at CFB Greenwood in March 1982. Later, it was also installed on a minicomputer at DREP to permit more effective response to questions from Greenwood regarding the version installed there.

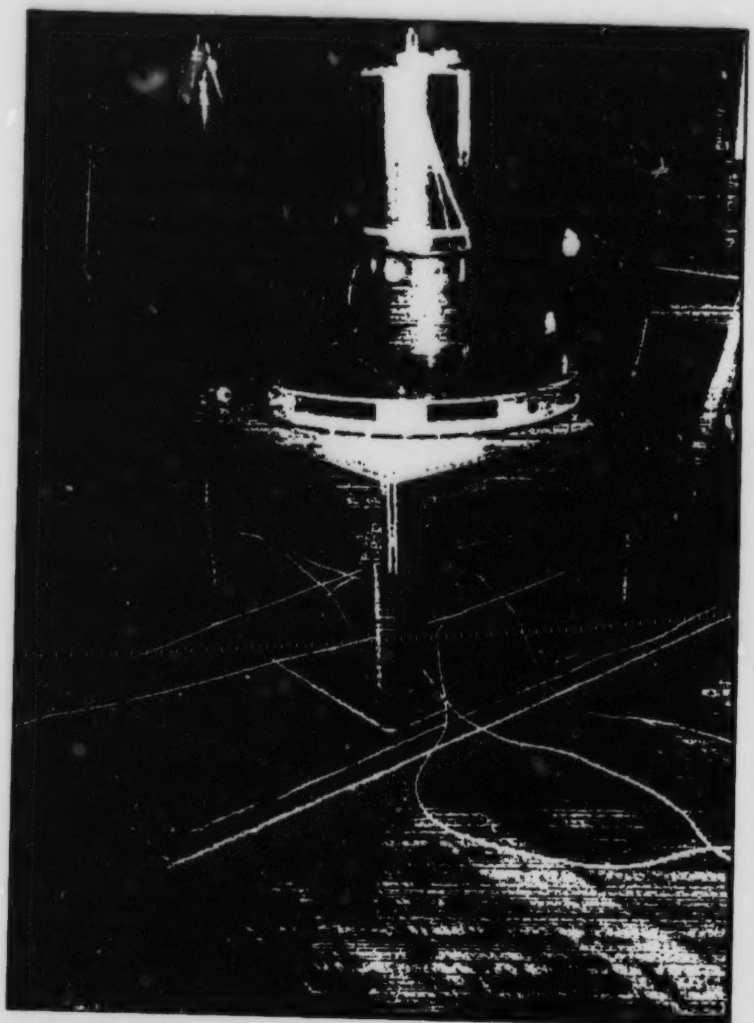
In November 1981, the multi-component gradiometer was towed along the Pitt River on a non-magnetic catamaran in order to obtain geological and target data from a moving system. The same experimental arrangement was employed in 1983 when a second trial was carried out in the Fraser River, this time using CFAV ENDEAVOUR as a stationary target. The tests indicated that although gradiometers showed considerable promise for detecting and tracking military targets, much work would need to be done to achieve this performance from an airborne installation. Accordingly, contracts were initiated with CTF to improve the performance of the gradiometer in a mobile environment. Design and manufacture commenced at DREP on a large helicopter-towed bird to house the gradiometer and associated test sensors.

Gradiometer being towed along the Pitt River

In 1985, a new facility for testing superconducting magnetometers was constructed at Rocky Point, located about 25 km southwest of Victoria. Construction included a hut for data recording and a non-magnetic tower for testing magnetometers and gradiometers in a low-gradient, low-noise environment. Harold Wilson and Mike Hayes, a visiting scientist from the UK, spent the summer of 1985 mounting a 3-axis set of 5-m square Helmholtz coils in the tower. The large coil size was chosen so that it would be easy to work inside the coils system without the coils interfering with the installation and movement of the rocker and gradiometer. This seemingly simple task took 3 months of carpentry and detailed surveying, but by the autumn of 1985 large coils had been constructed which generated a constant field over a 0.6-m per side cubic region at the centre of the coil system. A non-magnetic rocker for tilting the gradiometers was then installed at the centre of the coils. This permitted the testing of the response of gradiometers to changing magnetic fields and the separation of signals caused by mechanical effects, such as sloshing liquid helium and vibrations in the sensor, from signals due to changing projections of the magnetic field on the sensor. This significantly advanced the Laboratory's capability in MAD research and was essential for diagnosing problems in gradiometers and recommending design changes.

Magnetometer test facility at Rocky Point

Work also continued on the investigation of the properties of magnetic fields in northern waters. Having completed the investigations in Barrow Strait, attention—with the exception of a long-term study of two components of the micropulsation field being carried out using a sensor at Resolute Bay—shifted to other areas. In 1981, a line of magnetic sensors was deployed on the bottom at the western end of Jones Sound by the SIR JOHN A MACDONALD, which then served as a test signal for evaluating the effectiveness of DREP's noise cancellation and detection algorithms. In 1982, completely new, compact, light-weight, readily-portable electric and magnetic receiving systems were designed and constructed at DREP. They were then employed in an experiment conducted on the polar ice north of Alaska in co-operation with the Applied Physics Laboratory (APL) of the University of Washington and the USN.



Gradiometer being tested on rocker at Rocky Point

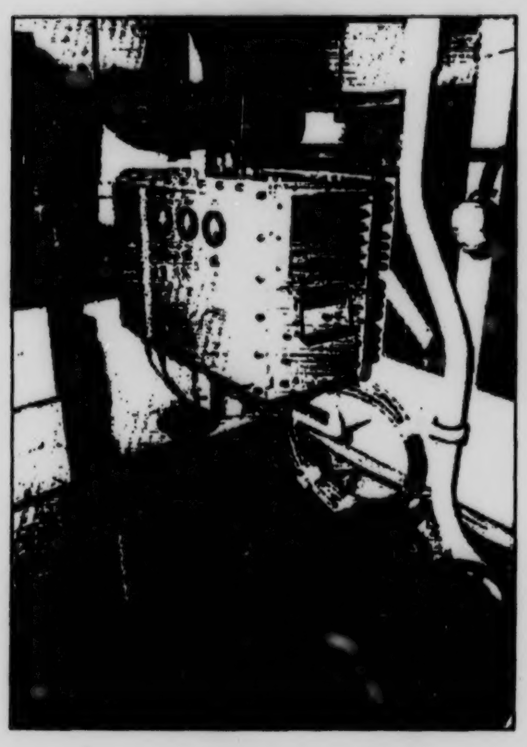
Mine Countermeasures.

Based on geopolitical considerations and information acquired through participation in TTCP Panel GTP-13, it had been evident for some time that mine countermeasures was due to receive a much higher priority in western navies, including Canada's. As a result, and after due consideration of CF requirements, it was decided to launch a program which would emphasize ship quietening and route surveying. In order to capitalize on the very considerable experience of the UK in these areas, Ron Kuwahara was sent to the Admiralty Underwater Weapons Establishment (AUWE), Portland, on a two-year posting beginning in mid-1983. Meanwhile at DREP, other scientists began to acquire the basic equipment and techniques required for route surveying. Fortunately, industry on the West Coast, including that in British Columbia, was heavily immersed in undersea technology and hence was particularly well placed to contribute to this endeavour. Thus, through off-the-shelf purchases and a number of contracts to adapt existing technologies to DREP needs, a respectable route surveying capability was soon

ISE DART ROV

established. This had progressed to the point where, in the fall of 1984, DREP was able to provide the Fleet Diving Unit (Pacific), FDU(P), with equipment—a 500kHz Klein sidescan sonar for locating mine-like objects, an International Submarine Enterprises (ISE) developed DART Remotely Operated Vehicle (ROV) fitted with a Mesotech colour sonar and a TV camera for identifying contacts, and an Offshore Systems Ltd Precision Navigation System for co-ordinating the positions of the sidescan sonar and DART—and advice on the planning of the exercise, the operation of the equipment, and the interpretation of the data. The divers reported that it was the most successful minehunting exercise that they had ever participated in, and they didn't even get wet. The mine counter-measures program received official approval in January 1984, with Ron Kuwahara as group leader. As the technology required for underwater electromagnetic surveillance using fixed systems possesses many elements in common with that required for mine countermeasures, the MCM group also took over responsibility for this activity as well.

The work on ship quietening by shaft grounding had progressed to the point where it was decided to transfer the technology to Canadian Industry—Davis Engineering came up with the winning bid—in order to place it in a position to respond to both national and international requirements. This resulted in the development of an active controlled-potential shaft-grounding system based on the DREP system evaluated on CFAV ENDEAVOUR. In 1982, the first model produced by Davis Engineering was installed on HMCS MACKENZIE for testing and to facilitate system upgrading. As a result of measurements of ship-radiated underwater electromagnetic signals by DREP and laboratories in allied countries, a greatly increased interest in ship quietening developed. This led to collaboration with the US and UK in research on extremely low frequency effects (ELFE) of surface ships. This resulted in 1984 in the testing of a Davis Engineering shaft-grounding system on a test rig at AUWE followed a year later by a sea trial at Fort Lauderdale comparing the performance on destroyers of this and competing grounding systems. The Davis system acquitted itself very well.

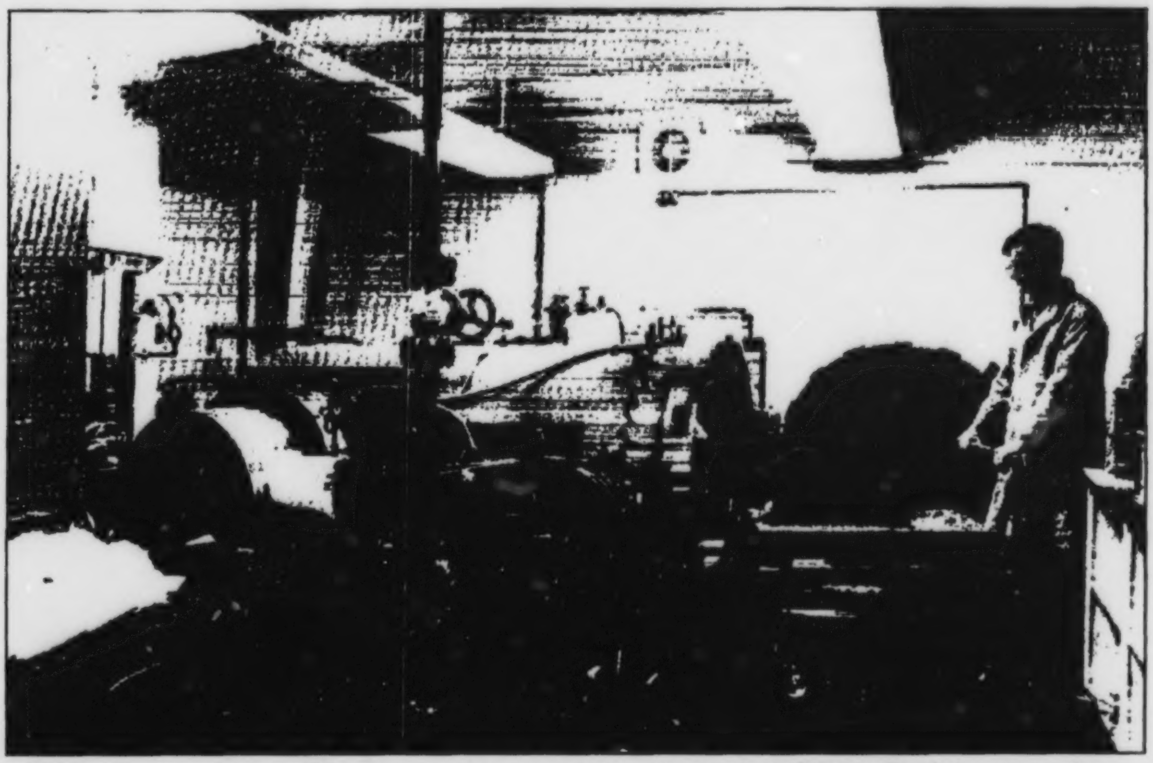


The controlled-potential shaft-grounding system

Materials Technology

In the early 1980s, the CF acquired a fleet of CF-18 jet fighters. In support of this acquisition, the work on advanced composites focussed on the mechanisms of in-service damage and into methods for repairing the damage. A significant accomplishment with respect to the structural integrity of the aircraft was the determination of the delamination mechanisms and the dependence of such mechanisms on the temperature and moisture content of the composite materials. In addition, a novel technique was developed to support the CF in their evaluation of the potential damage to the composite material in the aircraft's stabilizer during rocket firings. The technique involved bonding of composite specimens to the horizontal stabilizer, which is exposed to the direct heat from the rocket's exhaust. Firings at the Aerospace Engineering Test Establishment in Cold Lake showed that the method was successful for evaluating materials behavior in a real-life environment. The damage tolerance problem was also a primary topic of concern in TTCP Panel PTP-4 (Materials Performance in Systems); Canada acted as the project leader, with the UK, US, and Australia as the other participants. The commonality of the F-18, was the basis for this effort in international collaboration.

CF-18 carrying out firing tests of the DREV-developed CRV7 rocket at Cold Lake



Ernie Jensen placing fibre composite wrapped cylinder in DREP's Ecolaire Autoclave

The composite research program was advanced significantly with the development under contract—by Ecolaire Canada Ltd of Kitchener—of a prototype laboratory-scale autoclave for producing composite materials under highly controlled conditions. This was the first autoclave of this scale and type produced in Canada. Its excellent performance gave it a good potential for competing in markets both nationally and abroad.

The repair of graphite-epoxy wing skins and other composite structures requires a technology base in adhesive bonding. A program was therefore initiated by Dr G.A. (Greg) Luoma to examine the properties of commercially available adhesives with regard to their suitability in battle damage repairs, particularly those carried out in the field under less than optimum conditions. Having examined the alternatives, he then developed an adhesive with properties clearly superior to those of any commercially available product.

Motivated by an interest in nondestructive evaluation of defects in the CF-18, a study was undertaken of the use of robotics to improve the speed and reliability of flaw detection and to provide a permanent record of inspections. In addition to an in-house program to interface conventional inspection instruments with a commercial robotic arm, a local firm, RSI, was contracted to develop a prototype inspection arm for nondestructive testing of the CF-18 horizontal stabilator.

In engine health monitoring, refinements and improvements in obtaining diagnostic information from wear debris were continued. Analytical approaches applied included spectrometry, ferrography, particle counting and scanning electron microscopy coupled with micro-analysis methods. The more conventional SOAP method was applied to a wide variety of CF propulsion machinery to identify wear characteristics and forestall failures. A number of diagnostic surveys were conducted of propulsion equipment in machinery—primarily aircraft—where failure could be catastrophic. Surveys were conducted of engines in three types of helicopter, five types of aircraft including the CF-18, and the Leopard tank. By 1983, the increasing use of fine filters to remove damaging wear debris meant that an analysis of the debris in the lubricant was becoming less and less effective. In the CF-18, for example, virtually no wear debris remains in the lubricating oil. Accordingly, attention was now directed at the debris in the filters themselves, an approach which proved to work particularly well with the CF-18, based on an extensive fleet-wide investigation utilizing several advanced technologies. This approach was also applied to the Sea King main gearbox and the Buffalo aircraft engines which had been identified specifically as equipment items requiring improved engine health monitoring procedures. The approach also proved to be effective for monitoring wear in DDE ship machinery. Other projects completed at the time were: an investigation of an improved cathodic protection system—later installed on the AORs; testing of an anti-fouling paint which decreased surface roughness on ENDEAVOUR by 20% and reduced its power demand by 10%—later applied to the DDEs; the development of a 700 gallon per day reverse osmosis system for desalinating sea water—installed on ENDEAVOUR; and the development of a simple, cheap and effective instrument for detecting the emission of OTTO fuel from stored torpedoes.

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Harold Grant retired as Chief in October 1985. He was replaced by Dr T. (Todd) Garrett in March 1986.

When word was received that Treasury Board had approved a ten million dollar mainframe computer replacement program for DREP, Don Warren, the Director of Administration, presented Bob Chapman, the Acting Chief during the October 1985 to March 1986 interregnum, with the "Old-computer-demolition system MK 1"

1986 to 1995 - SPINNAKER - the Gulf War–closure

Organization, facilities and trends

Dr Garrett's initial employment in DRB was at DREO, where he was a mechanical engineer assigned to the Alouette satellite project. He later became the Space Craft Mechanical Project Manager for the Communications Technology Satellite. He and others, including John Mar—a former PNL employee—considered that an inflatable version of the deployable antenna concept used in the satellites would also have application in advanced sonobuoy developments. After initial trials in the Ottawa River, the project was transferred to DREA—the laboratory responsible for sonobuoy research and development—with Todd Garrett as project manager. Prior to his appointment to DREP, he was a Division Director at DREA.

Dr Garrett presiding over a November 1987 meeting of the DREP Management Committee - Bob Chapman, John Smith, Ray Brown, Ashton Patterson, Todd Garrett, Ralph Barer, Glenn Turner, Roy Erickson and Gordon Clark

Between 1978 and 1985, the number of civilian employees at the Laboratory had reached a plateau of around 136, and then entered a period of modest but steady decline; at the time of the announced closure in February 1994, the number had dropped to 120. Viability of the key research areas was maintained throughout this period by terminating the work on fluid dynamics and redistributing resources to other projects—particularly Arctic Acoustics—increasing the number of attached service officers from 4 to 5, making more extensive use of contractors in the research programs, and privatizing janitorial services and computer maintenance.

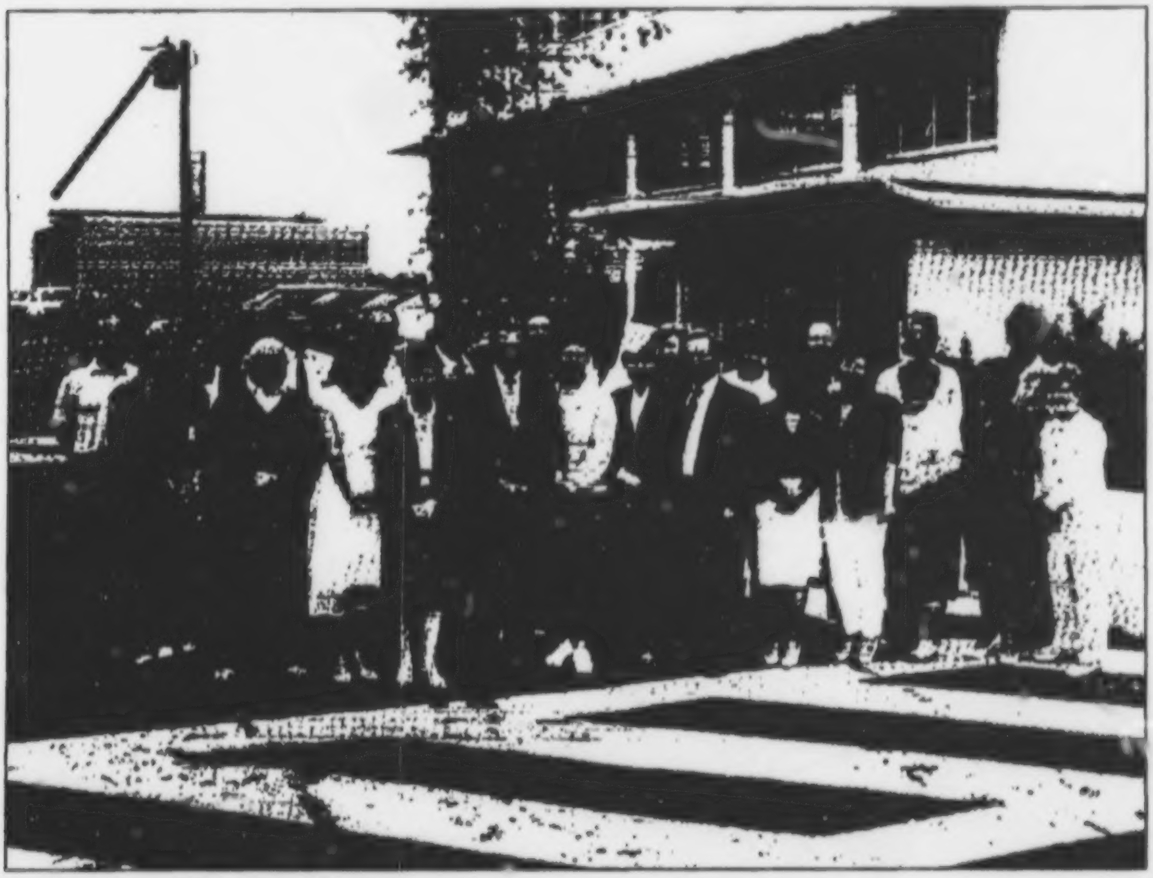
In spite of the decrease in staff, space was still at a premium. Thus, two more additions were made to the East Wing, in September 1986, a shielded computer room for classified processing, and in August 1987, office space for Ocean Acoustics—on the third floor—and for Engineering and Administration—on the second floor. As this essentially exhausted the expansion possibilities at the present site, and as Building 204, the home of approximately half the Materials Technology effort, was slated for demolition, planning began for the construction of a new laboratory across Esquimalt Harbour in Colwood. Although fairly detailed specifications were drawn up with the assistance of a firm of architects, the project was terminated in 1994 before actual construction began.

1994 photo showing DREP with all construction completed

Except for the termination of the work on fluid dynamics, followed by the creation of an Arctic Modelling and Simulation Group—led by Blyth Hughes from its inception in 1987 until his retirement in 1991 and subsequently by John Ozard—there were no other organizational changes.

A noteworthy personnel change took place in 1988 with the retirement of Ralph Barer—after leading Materials Technology for 36 years—and his replacement by Frank Peters.

CFAV ENDEAVOUR had begun to show its age, so it was subjected to a major refit, designed both to increase its usefulness for research and to extend its operational life for another 15 years. The refit, completed in 1989, included a new computer laboratory, a rebuilt and extended dry laboratory, an extended quarterdeck to make it more useful for towed array operations, a new radar and navigation suite, and extensive upgrading of the ships machinery and accommodations. There was, however, a downside to the refit. During the three years that the ship was effectively out of commission, all the navy staff at the Base involved in towed array operations with DREP disappeared, to the detriment of the corporate memory. By the time the problem had been rectified, the USSR submarine threat had subsided and the need for combined DREP/MARPAC towed array operations had become less compelling.



Although the overall number of staff declined over the decade, that in Administration held up very well, fuelled by increasing demands on safety and health, environment, security, and employment equity. The photo, taken in 1990, shows the Director of Administration, Victoria Adams, flanked by her staff. Front row: Laurie MacMillan, Frank Kenny, Amarpal Singh, Allie May McCarthy, Gene Field, Chris Brownlee, Victoria Adams, Laurance Stanners, Laurie Reid, Eloise Jones, Gerry Calver, Shanti Manhas and Helen MacBeth. Back row: Doug Fleming, Marilyn Anderson, Sid Hucyl, Terry Duncan, Ian Elder, Ken Kelly, Myrna Issac, Joanne Stone, Laurie Kerstin, Larry MacDermid, Bill Garcia and Wayne Locke.

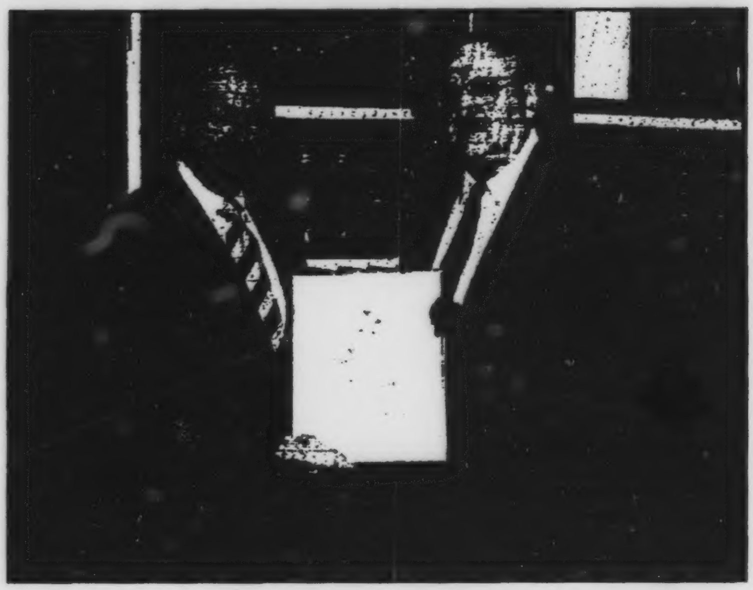
Dr Frank Peters and Dr Todd Garrett with the Minister of National Defence, Dr Tom Siddon, during the latter's farewell visit to DREP in July 1993. Dr Siddon was a summer research assistant at PNL in 1963 and worked on a number of engineering projects.

Ocean Acoustics

At the beginning of the program's final decade, the main focus was on the surveillance of the nuclear powered ballistic missile submarine operating in the deep waters of the Northeast Pacific. With the end of the Cold War—followed almost immediately by the 1990-invasion of Kuwait—concern in allied navies shifted toward the diesel-electric attack submarine operating in shallow water. Over the last half of the decade, steps were taken to make the programs, not only at DREP but throughout TTCP, responsive to this new concern. Steadily diminishing resources devoted to ASW in all countries made co-operation in joint experimental programs increasingly attractive. Ross Chapman became the principal Canadian contact for a TTCP action group set up to address this issue, resulting in DREP participating in TTCP sponsored shallow water experiments off New Zealand, Australia, and Canada's east and west coasts.

DREP staff—particularly Jim Kennedy, Glenn Turner and Dr D.W. (Dave) Craig—continued to be actively involved in system performance studies to help define the Department's requirements in maritime defence and the systems best able to fulfil these requirements. The 3S study, designed to specify a sonar suite for an anticipated purchase of diesel-electric submarines, was completed in 1987. Considerable interest was added by a decision of the sponsor—the Canadian Submarine Acquisition Program—to make a mid-study change in platform from diesel-electric to nuclear, a decision reversed shortly after the completion of the study. Some time later, in 1991 and 1992, a similar study was carried out to assess the performance of candidate arrays for the existing OBERON-class submarines. In 1986 and 1987, DREP contributed to the DREA-led Future Canadian Sonobuoy Concepts study, by providing noise and sound propagation models for the Northeast Pacific. It later provided similar information to support a Director Maritime Operation Research (DMOR) Atlantic/Pacific Surveillance Study. In 1987 and 1988, DREP also participated in a USCC action group and study in support of a position paper on CF requirements in ocean surveillance. In 1990 and 1991, DREP scientists played a substantial part in the CRAD sponsored—again at the request of the USCC—Canadian SURTASS Concepts Study (CSCS), designed to define system parameters, characteristics and capabilities for an operational SURTASS. The work at DREP centred on the requirements for the passive and active components of the acoustic surveillance system and included the integration of work on ship design carried out by DREA, and NDHQ directorates.

Since the mid-1970s, DREP and MARPAC staff had co-manned the towed array installation on ENDEAVOUR in at least one military training exercise or operation per year. Except for the period when the ship was in—or recovering from—a major refit, this continued. The recording and analysis gear used in the earlier exercises was the DREP data acquisition and analysis system augmented with military recorders for display. The technology for both was at least a decade old—an eternity in terms of computer development—so the decision was made to up-grade the system and, at the same time, include all-electronic displays to turn the installation into a state-of-the-art prototype surveillance system, well suited for feasibility demonstrations. Industry would be brought in both to leverage DREP's effort and for technology transfer. Also included would be a suite of passive ranging algorithms and a performance prediction system based on the PE sound propagation model.



The second CRAD, Dr Derek Schofield, presenting a TTCP-award to Bob Chapman recognizing the Establishment's achievements in towed array research

Advances continued in the development and implementation of the PE sound propagation algorithms. Dave Thomson applied his expertise in this area as consultant to CANARPS, an acoustic range (sonar performance) prediction system being developed by the Navy for the CPF. In support of this project, DREP developed[44] a stand-alone PE-Box—CANAPES I—for concept demonstration. The first sea- trials were carried out in 1987, a COAMS experiment in May and a military

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[44] Much of the work on this and the follow-on development, CANAPES II, was carried out under contract with BCS.

Dave Thomson working on the development of CANAPES, the Parabolic Equation based range-prediction system

surveillance exercise in September. The software was then delivered to CANARPS. The following year the stand-alone system was expanded to include wide-angle PE.[45] Between 1989 and 1991, a miniaturized version of the PE-Box, CANAPES II, was developed to take advantage of recent advances in computer hardware. It included options for beam-forming, modal decomposition and phase correction of PE wave fields,[46] and was designed so that new features could readily be added. CANAPES I, being no longer required in the Laboratory, was given to MARPAC in early 1992, thus permitting it to supply improved quality acoustic propagation predictions to the fleet. In July, it was loaned to a US warship participating in a major military exercise, where it received an enthusiastic endorsement. The effectiveness of CANAPES II was demonstrated on a matched field experiment and in a military exercise, in 1992 and 1993 respectively. On the latter trial, the equipment on ENDEAVOUR was again co-manned by DREP scientists and by military and operational research personnel from MARPAC.

Replacement of the dry-end of the towed array installation on ENDEAVOUR began in 1988 with the purchase of a MASSCOMP computer, a high speed data acquisition system and colour displays. A smaller MASSCOMP was also purchased for use in a research contract with CDC to implement real-time tracking using TMA algorithms. When completed, the algorithms were integrated into the new data processing system. Most of the system integration to produce a functional system was carried out under contract. A research contract with BCS to process and display data in lofargram[47] format on an image processing system was completed in 1990. The first sea-trials of the system took place in September 1991. Additional contracts followed to improve the resolution of the lofargram displays and to integrate environmental and other non-acoustic information, such as ship speed, heading and position, into the data stream. The system was then operated successfully against realistic targets in military training exercises conducted annually between 1992 and 1994. Prior to each trial, improvements were added to the system, based on the technology being developed in the Group and on the experience gained in earlier trials. Considerable progress was made although the changed world situation effectively side-lined the anticipated definitive demonstration.

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[45] A modification developed by Dave Thomson and Ross Chapman to improve the accuracy of PE algorithms. Published in a frequently quoted paper in the Journal of the Acoustic Society of America.

[46] More recent developments at DREP to further improve the accuracy of PE in range-dependent environments.

Emphasis was given to the investigation of techniques for obtaining improved range and bearing of targets from passive sonar arrays, furthering their development in industry,[48] incorporating them in the seagoing data acquisition system, and demonstrating performance in operational situations. In a number of military exercises, contact was obtained against real targets and the raw acoustic data recorded on tape. In the most interesting cases the Navy carried out extensive post-exercise analyses to determine the location and operational behaviour of the various participants. Thus, for its last decade, the Laboratory possessed an extensive data base which could be used to demonstrate the effectiveness of its various detection and tracking algorithms operating under realistic conditions against real targets. By 1988, the in-house research on wide-band multi-path passive ranging had been completed and the results passed to CDC for further development and exploitation. A year later, a similar situation occurred with TMA, which was farmed out to CDC to produce interactive software for the DREP sea-going data acquisition system. The scientific staff then concentrated on two other passive ranging techniques, Space-Time Integration (STI) and matched field processing.

STI is a technique, developed by Mr B.H. (Brian) Maranda,[49] which integrates the signal from a target along a very large number of possible tracks, the maximum signal output occurring when the track, speed, and radiated signal of the assumed target most closely matches those of the actual target. The very long integration periods inherent in this method—an hour would not be unreasonable—results in reliable tracking being achieved in situations where conventional methods—with short integration periods—might not even be alerted to the presence of a target. The technique was demonstrated successfully at sea against a low-signal target in June 1992. A contract was then let to IOTEK—situated in Halifax—to design a hardware based STI system prototype.

In 1986, 1988, 1991 and 1992, a rewarding series of sound propagation trials—designated PACIFIC ECHO—was carried out in the Northeast Pacific in co-operation with NRL. Experiments emphasized matched field processing and the measurement of the acoustic properties of the ocean environment, particularly of the bottom, which impact most strongly on this process. During the series, the feasibility of matched field target localization was investigated using both horizontal and vertical line arrays. For horizontal arrays the method was observed to be most effective at end-fire, with performance enhanced by a modest slope to the towed array to give it some vertical aperture. Vertical line arrays also provide good localization performance based on a simple but realistic model of the ocean and bottom environments and a precise knowledge of the array geometry. Of course, in a situation where the sound propagation is independent of azimuth, the vertical line is ineffective for providing bearing information. However, in some circumstances, particularly those found in shallow water, sound propagation can depend quite strongly on azimuthal direction and, under these conditions, matched field processing of vertical line data can, in principle, also provide the bearing. This concept of environmental signal processing was pioneered by NRL who developed the Wide-area Rapid Prediction (WRAP) computer program for its implementation. The WRAP model was introduced at DREP in 1991 to permit the analysis of the vertical line data collected that year in the Pacific Echo III experiment.

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[47] A lofargram is a commonly used display in underwater acoustic surveillance systems. Traditionally it displays acoustic intensity as a function of frequency across a rolled-paper chart and of time along the chart. In the updated system the paper-chart was replaced by a computer screen.

[48] Although several companies were involved in the various phases of the passive-ranging research, most of the interactions at this time were with CDC.

[49] Brian Maranda received a US patent on his invention in 1996.

As a result of growing interest in TTCP in the detection, tracking and localization of diesel-electric submarines operating in shallow water, Panels GTP-9 and -10 co-sponsored an experimental program in this area. As part of the US contribution to this endeavour, NRL also supplied the WRAP model to the other countries and took a leading role in the design and conduct of the experiments. DREP was also an active contributor to these TTCP-initiated experiments. In May 1993, John Fawcett participated in the on-site analysis of data collected in the TESPEX I experiment conducted to investigate matched field target localization in the shallow waters off New Zealand. In September of the same year, DREP also participated with the Applied Physics Laboratory (APL) of the University of Washington in an experiment on the continental shelf and slope off Vancouver Island to investigate the effect of environmental signal processing on target location using a long vertical array. In 1994, two members of the DREP staff participated aboard the DREA research ship QUEST in the TTCP-sponsored TRIAL SCOTIAN, an experiment studying environmental signal processing in East Coast shallow waters. In addition, John Fawcett participated in TESPEX II, an experiment in the shallow waters off the north coast of Australia to further the investigation of matched field target location using a multi-element vertical line array. This burst of TTCP-sponsored collaborative activity resulted both from the reduction in resources in all countries, which made it more difficult to conduct large scale experiments nationally, and their desire to extract more value for their contributions to TTCP. Whether or not this is the wave of the future is unclear, as a number of those laboratories and programs which were most amenable to international co-operation have been extremely hard hit by the current wave of re-engineering and downsizing. This is expected to impact negatively on the personnel exchanges[50] sponsored by TTCP Subgroup G's Sonar Technology Panel (GTP-9), an activity which contributed substantially to the effectiveness of CRAD's ocean acoustic programs.

The reduced military threat led to the employment of resources developed for defence to support other national objectives, particularly those associated with the protection of the environment. One such effort was the Heard Island Feasibility Trial (HIFT), organized by Walter Munk of the Scripps Institute of Oceanography. The objective was to place the subject of global warming on a solid scientific basis by measuring the transit times of sound propagated over very long transmission paths in the ocean—the warmer the temperature the shorter the transit time. In an experiment conducted in 1991, sound transmitted from a ship off Heard Island near Antarctica in the Indian Ocean was received at many listening stations, including a number in the northern hemisphere. Remarkably, the same sound pulses were received on towed arrays operated by DREA off Nova Scotia and by DREP off California. The sound paths were impressive; that which conducted the sound to California,[51] first went south of Australia and then to the east of New Zealand before heading into the North Pacific. The path was 17,400 km long and the sound took three hours and seventeen minutes to arrive. The feasibility of the concept was demonstrated and an international consortium intends to set up a number of sound transmitting and receiving stations around the world to monitor the situation over decades. With the closure of DREP, any DND connection with this project in the Pacific terminated; there is still, however, some involvement in the far north—an area expected to be particularly influenced by global warming—where sound has been received from a Russian transmitter situated across the Arctic Basin.

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[50] Between 1982 and 1994, there were a number of exchanges of scientists involving the DREP Ocean Acoustics Group: from DREP; D.J. Thomson to NUSC(US), Jun 82-Oct 84; N.R. Chapman to DSE(NZ), Oct 86-Apr 88; J.A. Fawcett to DSTO(AUS), Jan 91-Jul 92: to DREP; D.G. Browning from NUSC, Nov 82-Nov 83; J. Syck from NUSC, Apr 84-Oct 85; E.K. Westwood from ARL/UT(US), Aug 93-Aug 94.

Arctic Acoustics

Except for providing consulting services to the CF and winding up sound propagation studies in Barrow Strait, the main effort was now concentrated on the technical problems associated with underwater acoustic arrays in the Arctic Basin, their design, installation and the efficient processing of the data resulting therefrom. The problems faced were formidable. Tackling them required the combined expertise of DREP, several US laboratories—NRaD, NRL and NORDA[52]—and industry in both countries, with costs shared equally by Canada and the US.

By 1988, it became evident that suspending hydrophone arrays under the iceplugs or ice-shelves of Ellesmere Island would not be an optimum way of deploying Arctic acoustic systems. Hence, a decision was then made to look into the feasibility of placing a major experimental underwater installation under the Arctic icepack several tens of kilometres north of Ellesmere Island. The array was to have an unattended working life of several years, and be connected to shore by cable. The problem of taking the cable through the shoreline had been solved in principal by DREP and the technology for long-life, low-power acoustic receiving systems was well advanced in the US. The peculiar problem in the Arctic was to position and install the array from the moving Arctic icepack, to lay the cable under the ice and connect the two together, all carried out at -40°C at the end of a long and difficult logistics chain. In spite of, or perhaps because of, these difficulties the pressures to get it right the first time were enormous. DREP, emboldened by the presence in Vancouver of a substantial industrial capability in under-water vehicles, agreed to become responsible for the technically most risky component of the operation, namely, taking the cable through the shoreline and delivering it to an icefloe above the US produced and installed array. The development of signal processing techniques and the data analysis were to be a shared responsibility. By mid-1988, the critical technical areas of the project and the responsibilities of the various participants were defined in general terms. By this time, the US[53] was able to confirm its interest in such a shared-cost activity—code named SPINNAKER after the well known Victoria pub in whose ambience were made many of the project's more thoughtful and far-reaching decisions. The political climate in Canada was also conducive to the launching of the project as soverignty in Arctic waters was given a high priority in the 1987 White Paper on Defence.[54]

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[51] The DREP scientists involved in the experiment were Ross Chapman and Garry Heard—yes, it is believed that there is a family connection with the island. Much of the analysis was carried out at JASCO, a company owned by a former DREP scientist, Joe Scrimger.

[52] Naval Ocean Research and Development Agency, Bay St. Louis, Mississippi.

[53] The project was also enthusiastically endorsed by an influential CAN/US committee, the Senior National Naval Representatives (SNNR), an event which proved crucial to it receiving formal approval by both countries.

> Over the past two decades, with the development of nuclear power, the Arctic has become an operating area for submarines. Deep channels through the Canadian Arctic offer a means of passing between the Arctic and Atlantic oceans. In periods of tension or war, Soviet submarines could seek to operate off the deep channels of the Canadian Archipelago to intercept Allied submarines entering the Arctic. Moreover, the Soviets might use these channels in war to reach patrol areas in the North Atlantic, including the Labrador Sea. In light of these circumstances, the Canadian navy must be able to determine what is happening under the ice in the Canadian Arctic, and to deter hostile or potentially hostile intrusions.

It was agreed that the most difficult part of the project would be the laying of a 220-km fibre optic telemetry cable under the ice from the shore to the array. The most promising approach was to use an autonomous underwater vehicle (AUV), such as the *ARCS* constructed by ISER and owned by the Canadian Department of Fisheries and Oceans. ISER had investigated the various options and costs of using a modified *ARCS* or a specially built AUV and concluded that the best prospect for success would be to refurbish *ARCS* for use in cable laying trials in the South, and to incorporate the technology developed and the lessons learned in a larger purpose-built AUV for carrying out the actual operations in the North. In 1989, *ARCS* was taken out of storage and a series of sea trials was conducted to evaluate the vehicle's reliability and its capability for conducting the required cable-laying tests. The vehicle was then updated by installing new hydroplanes, propulsion motor and motor controller. Contracts were let to investigate control system architecture and to design, construct and test a fibre optic cable module and buoyancy compensation module for the *ARCS*. Tests were carried out successfully in the fall of 1990 when the fully submerged *ARCS*, operating in a completely autonomous mode, laid several kilometres of fibre optic cable, thus demonstrating the concept. Design studies were then progressed for the larger vehicle and the associated long-distance navigation and autonomous control systems required for the Arctic operation. A year later, the navigation and control systems were installed and tested on the *ARCS* and a contract was let to determine the specifications for an obstacle avoidance system.

Cable-Laying AUV Specifications. [55]

- vehicle endurance (distance) – 450 km
- vehicle endurance (time) – 72 hours
- cable capacity – 220 km
- vehicle operating depth to1000 m
- Obstacle Avoidance Sonar system
- acoustic homing from ranges of approximately 10 km in 500 m-deep water
- cruising speed – 4 knots
- modular construction into sections weighing less than 1,350 kg

By 1992, the general requirements having been determined, ISER began the development of *Theseus*,[56] a large cable-laying AUV suitable for extended operations in the Arctic. It was an ambitious undertaking, with the vehicle, designed to carry out a fully autonomous cable-laying mission of up to 350 km, operating in a bottom following mode at depths to 1,000 m, with navigation accuracy better than 1% of the distance travelled.

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[54] "Challenge and Commitment—A Defence Policy for Canada," National Defence, June 1987.

[55] J.M. Thorleifson, LCdr T.C. Davies, M.R. Black, D.A. Hopkin and R.I. Verrall (EDRD), and A. Pope, I. Monteith and B. Butler (ISER), "*Theseus* - A Precision Autonomous Delivery Platform for Underwater Sensors and Systems." Subgroup G Symposium on Shallow Water Undersea Warfare. Halifax, NS, (October 1996).

[56] *Theseus* was named after the mythical Athenian prince who slew the Minotaur in the Cretan labyrinth and escaped by following a thread which he had dispensed during his entry.

Theseus is a large cylindrical vehicle with a length of 10.7 m, a diameter of 1.27 m, and a weight of 8,600 kg. The pressure hull consists of five identical 3.4-cm thick aluminum sections and two end caps. The modular design allows the pressure hull to be disassembled for transportation in small aircraft, a particularly important feature for operations in the North. The vehicle has two separate compensation systems: a variable ballast system—consisting of two large toroidal tank/pump combinations located fore and aft—to provide a sufficient range of buoyancy for parking the vehicle either on the bottom or under the ice surface—and a separate system to compensate for changes in buoyancy as trunk cable is deployed. An obstacle avoidance sonar was also installed to ensure that the vehicle would not crash into bottom features or ice keels. Acoustic telemetry and homing systems were also essential for the cable laying mission. Vehicle navigation systems included an inertial navigation unit for heading reference, a doppler sonar operating in bottom mode for ground speed, plus terminal acoustic homing systems. The inertial navigation-doppler sonar combination provided an overall navigation error that was less than 1% of the distance travelled. During the mission the vehicle position can be updated at acoustic beacons located along the route and also at the cable delivery site. On the outbound leg of the mission, the vehicle status is sent to the launch site over the fibre-optic trunk cable. In addition to sending critical vehicle status information such as battery condition, position and vehicle attitude, this link also allows the vehicle operator to assume control of the vehicle if the need arises. For example, if the vehicle is going off course, the operator can assume control and pilot it back to a safe place. In the event of a critical fault such as a loss of power, the vehicle will settle safely on the ocean bottom and await instructions either through the fibre-optic or acoustic telemetry systems, the latter having a range of from 5 to 8 km depending on conditions. If *Theseus* develops a major fault and settles on the bottom, emergency beacons on the vehicle automatically activate to assist in localization. Once located, a small icecamp is set up for emergency recovery. A small ROV then attaches a rope to a lifting lug on *Theseus* and returns to the surface. *Theseus* can then be pulled to the surface and corrective action taken.

As the vehicle moves forward above the seafloor, the fibre-optic cable is dispensed out the stern. When Theseus delivers the fibre-optic cable to the array site, it flies through a wire catchment triangle suspended from the ice surface. After passing through the triangle, the cable slowly sinks into a saddle located at the bottom of the triangle. The saddle is then brought to the surface and the cable recovered, spliced to the array cable and lowered to the ocean bottom.

Fabrication of the vehicle and the installation of the major navigation and control systems took place in 1994 with sea trials in the local area beginning in September. The first trials in the Arctic took place in April 1995 in the shallow ice-covered waters of Jolliffe Bay located approximately 6 km northwest of CFS ALERT. The objectives of the trials were to verify launch and recovery procedures, test all vehicle systems in an under-ice environment and demonstrate trunk cable recovery techniques. A total of four under-ice dives were carried out with the longest covering a distance of 5 km. The fibre-optic cable was left on the bottom to provide some information on its long term survivability.

The next *Theseus* trial, to test its long-range endurance and navigational accuracy, was successfully conducted at the Nanoose tracking range from 23 to 26 January 1996.[57] In a series of runs, the navigational accuracy was found to be very much better than specified, the homing systems worked well and the total distance traversed of 360 km indicated that all systems were go for the cable laying in the Arctic, an operation full of adventure but none the less outstandingly successful.

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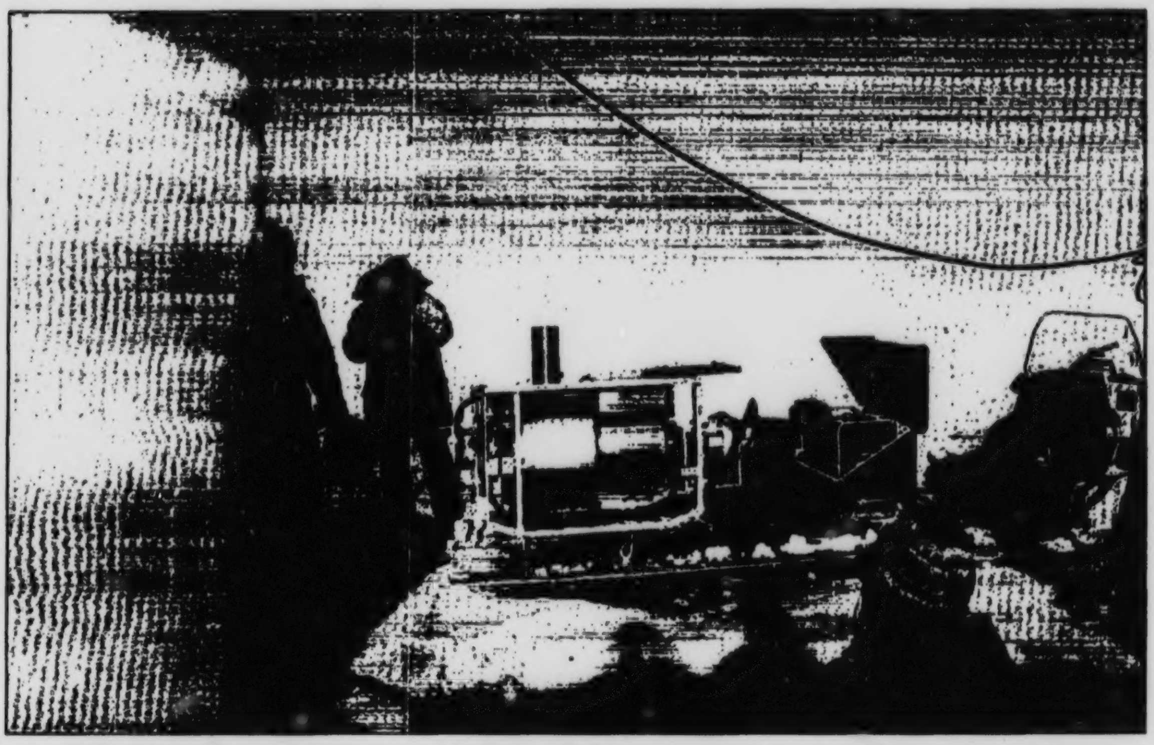
[57] Because of the extensive investment in, and the international commitment to, the project, it was continued at the Esquimalt Defence Research Detachment following the closure of DREP.

Dave Baade preparing a landing strip using the *Groomer*

Overlapping the development of *Theseus* was the search for a suitable array location and cable entry point. As the former depended critically on ambient noise and sound propagation, measurements of these quantities were made at a number of locations using a variety of horizontal and vertical arrays. The results of the experiments were fed back into the ongoing system and array design studies which then influenced the design and complexity of later experiments. The measurements were made each spring—when the ice was solid enough to support icecamps and the light was adequate for conducting field trials. In 1987, measurements were made using a 5-element vertical line array. A considerably expanded effort took place the following year with a variety of receiving arrays, including three vertical lines spaced about 2 km apart and thirty single hydrophones arranged in various horizontal configurations. A major co-operative field trial took place in 1989 at the edge of the continental shelf ninety miles north of CFS ALERT with measurements being made from a 6.4 km long, 30-element horizontal line array and a 500 m long, 32-element vertical array supplied by DREP and NORDA respectively.

The following year, acoustic measurements were made using a 500-m VLA and several smaller VLAs supplied by the US laboratories, and a DREP-supplied 900 m long, 10-element horizontal line array suspended close to the bottom. At this time, the US was developing techniques for installing arrays on the bottom and, in 1991, successfully deployed a large winter-over array. The array site having been selected, bathymetric surveys were conducted to aid in the selection of a suitable route for the fibre-optic cable. These were continued the following year, as was an investigation of the proposed cable landing site at Stuckberry Bay, 100 km east of Alert.



Feasibility demonstration site kept icefree by circulating hot water with icedrill

At this location, the DREP hot-water melter unit was combined with special cookie-cutter drill heads to cut a 4x2.5-m hole through 2.5 m of ice, thus demonstrating that the problem of creating a hole to get in and out of the water was solved, at least in principal. Three attempts to drill holes through the beach for cable entry were largely unsuccessful due to the soft nature of the bottom sediments. This, combined with improvements in fibre optic technology, the growing confidence in *Theseus* being able to handle the extra distance, and the very considerable savings resulting from the elimination of telemetry transmission back to Alert, led to a search for a more congenial environment close to the Base. In 1993, preliminary investigations were conducted at Jolliffe Bay which was only 6 km from Alert, possessed a geology more suitable for drilling and had water depths off-shore deep enough for operating *Theseus*. Test drilling and a bathymetric survey of the area confirmed the selection and the next year, a successful slant hole was drilled under the beach. As mentioned earlier, under-ice trials were conducted at Jolliffe in 1995, with *Theseus* launched and recovered through a 13x1.5x1.5-m hole cut into the ice.[58]

Throughout the decade Dr P. (Pierre) Zakarauskas conducted investigations of ambient noise in the Arctic, initially from ice-plugs along the northwest shore of Ellesmere Island and later out in the Basin at the SPINNAKER site. Two dominant noise mechanisms, ice-cracking and ridge-building, were found to account for most of the features observed. The former is a short-range effect that contributes to the observed noise field for only the first few kilometres. The latter effect dominates at long ranges. As ridge-building takes place over an extended period of time and at specific locations, it was possible to study individual events. Later the results from a number of events were combined to obtain an empirical model of a single ridge-building event. As the investigations progressed, a series of increasingly detailed models, combining the characteristics of both ice-cracking and ridge-building were developed. By 1995, the emphasis was on the determination of the distribution of the ridge-building events and its employment in system studies designed to define the optimum configuration for the SPINNAKER arrays. As most of the noise detected by these arrays would be due to ridging, and hence arising in a finite number of essentially fixed locations, very significant gains in performance should be achievable using matched field processing.

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[58] A hot water cutter sections the ice into manageable blocks which are then lifted by a gantry and moved away from the hole. The technique for making the hole through the ice and keeping it from freezing was developed by Ron Verrall and Dave Baade. For the trials involving the launching and recovery of Theseus the hole was kept ice-free by enclosing it in a large heated tent.

Initially, the installation in the Strait of Juan de Fuca was used as the platform for testing and evaluating MFP algorithms. However, it was superseded in 1989 by the various arrays used in the northern deployments. In developing detection and tracking algorithms extensive use was made of simulation. These studies initially covered stationary targets operating in range-independent environments but were later expanded to include moving targets in range-dependent environments. To be effective, MFP requires realistic propagation models, and hence a knowledge of acoustic properties of the bottom over the range of bearings and distances concerned. Generally, the better the knowledge, the better the performance of the array. However, measuring the desired acoustic parameters of the environment directly is both difficult and time consuming in an ice covered environment. Once again, MFP to the rescue through an inversion process; when operating with a known source, the process can be turned around to yield the acoustic parameters in the area covered by the trial. As a result of a number of trials, a knowledge of the relevant acoustic properties can be built up. Thus for a fixed installation, as knowledge is accumulated over the years and utilized, the gains from MFP should continue to accrue. The work on inversion was initiated by Dr S.E. (Stan) Dosso in 1992 and grew to become an important component of the Arctic program. Although by this time the improvement in array performance in an Arctic environment due to MFP had been effectively demonstrated, the process was still far from real time. Hence considerable effort was then devoted to techniques which would speed up the process to the point where it would become operationally viable. Neural networks and nearest-neighbor tracking algorithms developed by John Ozard promised over an order of magnitude speed-up in performance; this, combined with the rapid improvements in the speed of computers, indicated that MFP had the potential for effective real-time operation.

The investigation of sound propagation in the Arctic continued with experiments at the various sites of interest, the development of models required to interpret the acoustic measurements, and the ancillary measurements of the acoustic properties of the ocean bottom required as inputs to the models. The responsibility for modelling, primarily that of Gary Brooke, was shared with Blyth Hughes and Trevor Dawson following the termination in 1987 of the fluid dynamics project and the initiation of the Arctic Modelling and Simulation Group.

Some acoustic work associated with the channels continued, primarily in support of the ultrasonic modelling carried out under contract by SONOQUEST. Their model, which included a rough surface, indicated that air filled cracks have an important effect on sound propagation and that the width of ridges plays an important role in determining its frequency dependence. This was in accord with earlier measurements in Barrow Strait which showed that propagation velocities in smooth annual ice were significantly greater than those in a mixture of annual and multi-year ice. This observation was made quantitative through seismic experiments carried out in 1987 and 1988 which produced velocity and attenuation values for both

Hole drilling installation at Jolliffe Bay

annual and thick multi-year ice. This effectively completed the program of acoustic measurements in the Arctic channels which had been initiated three decades earlier.

Four propagation models were developed to cope with the complexity of sound propagation in the Arctic Basin: normal mode codes that model isotropic range-independent environments, coupled-mode and boundary integral codes that extend normal mode models to realistic 3D environments, and PE codes that efficiently handle propagation involving variable bathymetry, backscattering, elastic bottoms and surface roughness. These codes were intercompared for certain test cases and then tested against field measurements taken at the SPINNAKER site from 1990 to 1992. An excellent opportunity for additional model testing arose the following year when it became possible to co-operate with the Ocean Acoustics Group in a sound propagation experiment in the waters of the continental shelf off Vancouver Island. As a result of the extensive effort in sound propagation modelling conducted over many years, DREP was in the fortunate position of being able to rise to the challenge presented by matched field processing, both in the Pacific for towed and fixed arrays and in the Arctic by SPINNAKER.

SPINNAKER was undoubtedly the most extensive project ever undertaken by DREP. It involved directly some 25 of the Establishment's scientists and technicians[59] and at least comparable numbers from the various US laboratories co-operating in the project. The field trials involved as many as 91 participants, when aircrew and logistics personnel are included. It required an immense amount of dedication from all those involved, particularly from the Project manager, Jon Thorleifson. The technical problems to be solved were formidable, and the administrative difficulties only slightly less awesome. Although the project was conceived

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[59] The DREP project team consisted of: Jon Thorleifson (project manager); LCdrs Peter Lenk and Tudor Davies (deputy project managers); Ron Verrall (cable and array deployment, system installation); John Ozard (signal processing and modelling); Merv Black (array systems and data transmission); Dave Hopkin (underwater vehicle technologies); Steve Taylor (logistics co-ordination, ROV operation and signal processing systems); Linda Churcher (logistics co-ordination); Dave Baade (mechanical systems design/installation); Gordon Ebbeson and Maureen Yeremy (environmental analysis); Steve Kilistoff (data recording, processing and analysis systems); and Brendan Donald (logistics), Jim Milne (communications), Jim Perkins (communications, array systems), Bob McLean (electronic systems), Darryl Gittins, Dave Berger, Bob Rodger, and Colin Ganton provided field trials support. Capts Garry Hare, Ken Ujimoto, John Phillips and Richard Van Der Pryt were military liaison officers. Jim Kennedy, the Section Head, was a member of the joint Can/US steering committee tasked with the overall management of the project.

Ken Peebles, the third CRAD, presents a twenty-five year plaque to Jon Thorleifson, the Group Leader of Arctic Acoustics and the Canadian Manager for Project SPINNAKER

in 1988, it took four years of intense effort to gain the necessary approval and financial support from senior levels in both Canada and the US.

The actual installation took place during ICESHELF'96, in April 1996, when the array and cable were successfully deployed and connected. Although technically, ICESHELF'96 is outside the time frame of this history, it deserves to be mentioned as it marks the culmination of decades of research in the Arctic and is the crowning achievement of Project SPINNAKER.[60] The photographs on the next several pages have been selected to illustrate the scale and complexity of the operation.

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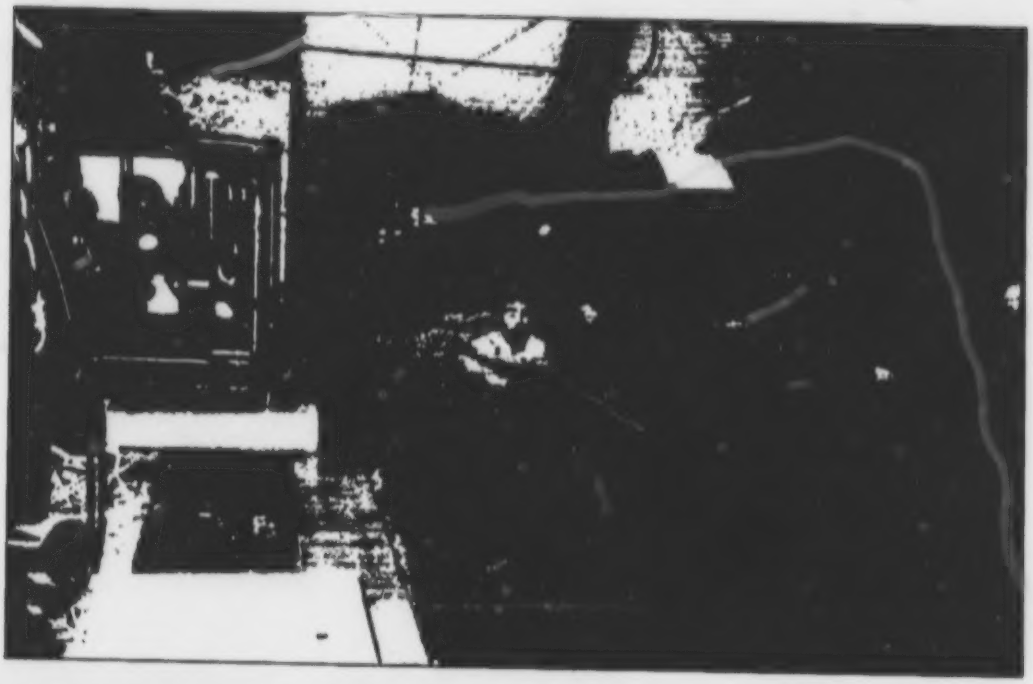
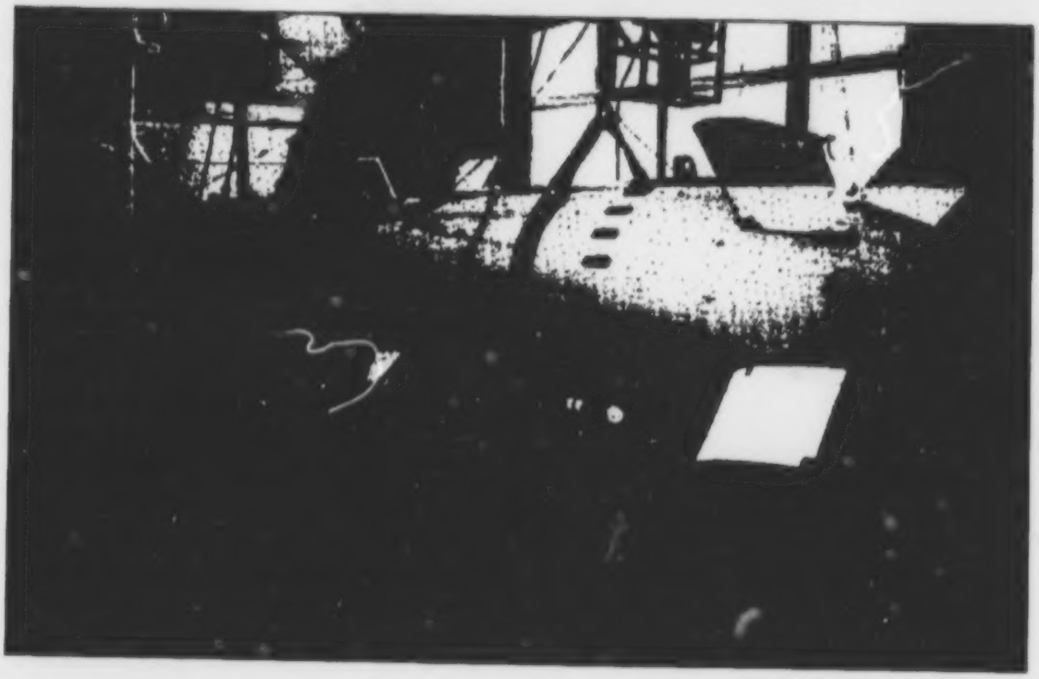
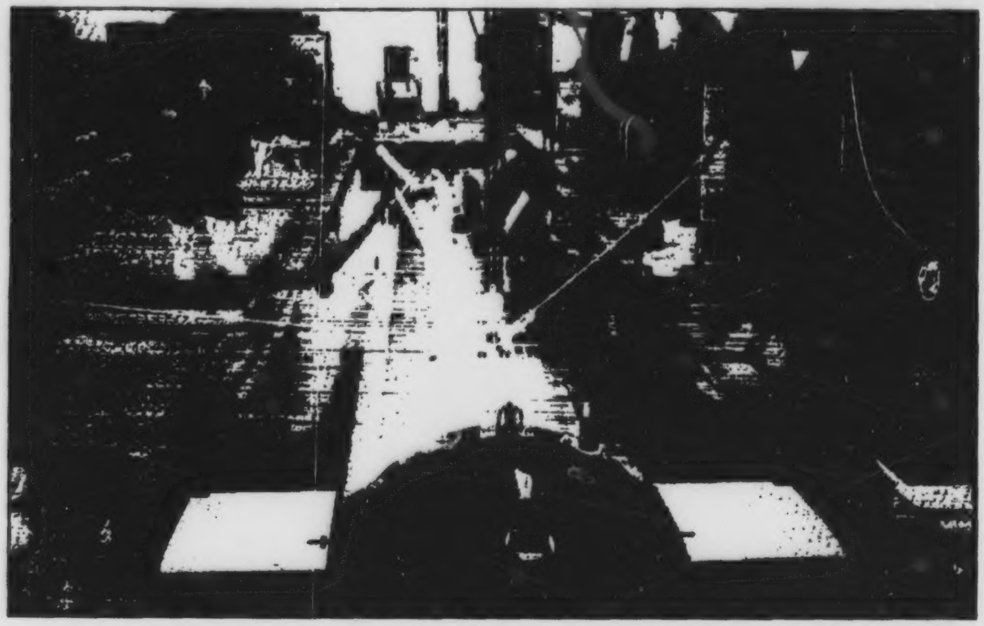
[60] For several weeks following the installation a copious supply of ambient noise data was received and recorded at CFS ALERT before a fault near the array closed down the operation. An attempt in the spring of 1997 to effect the required repairs was only partially successful; satisfactory techniques for repairing cables were demonstrated but additional damage and adverse weather conditions prevented the system from being restored to operability in the time available. A follow-on repair operation is scheduled for early 1998.

(top) As the number of participants in the month-long ICESHELF'96 well exceeded the accommodations available at CFS ALERT, personnel were flown into the Arctic only when their services became essential. Thus only about two thirds of the 91 participants were available for this photo opportunity. (bottom) Barbara Sotirin the US project manager.

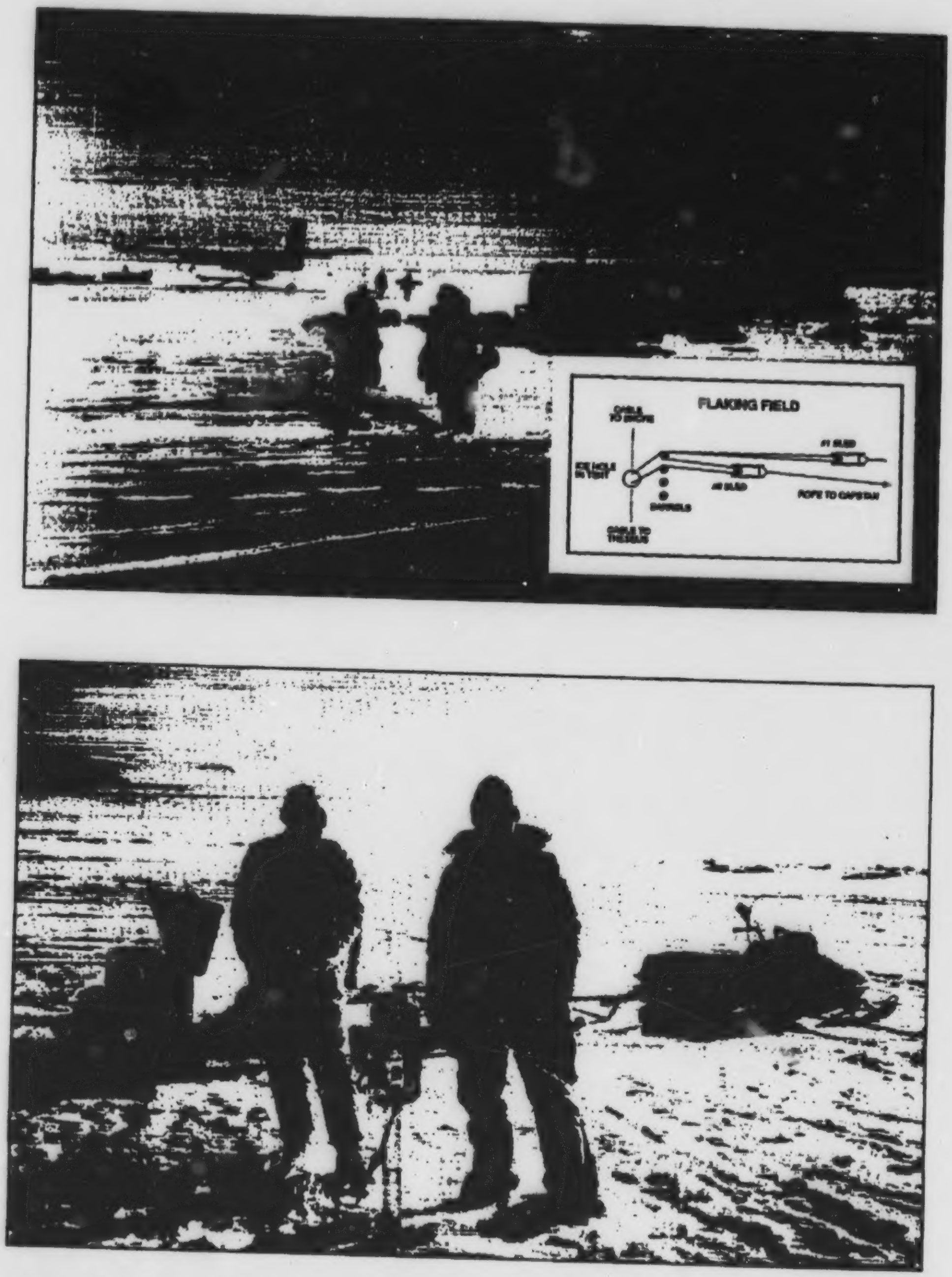




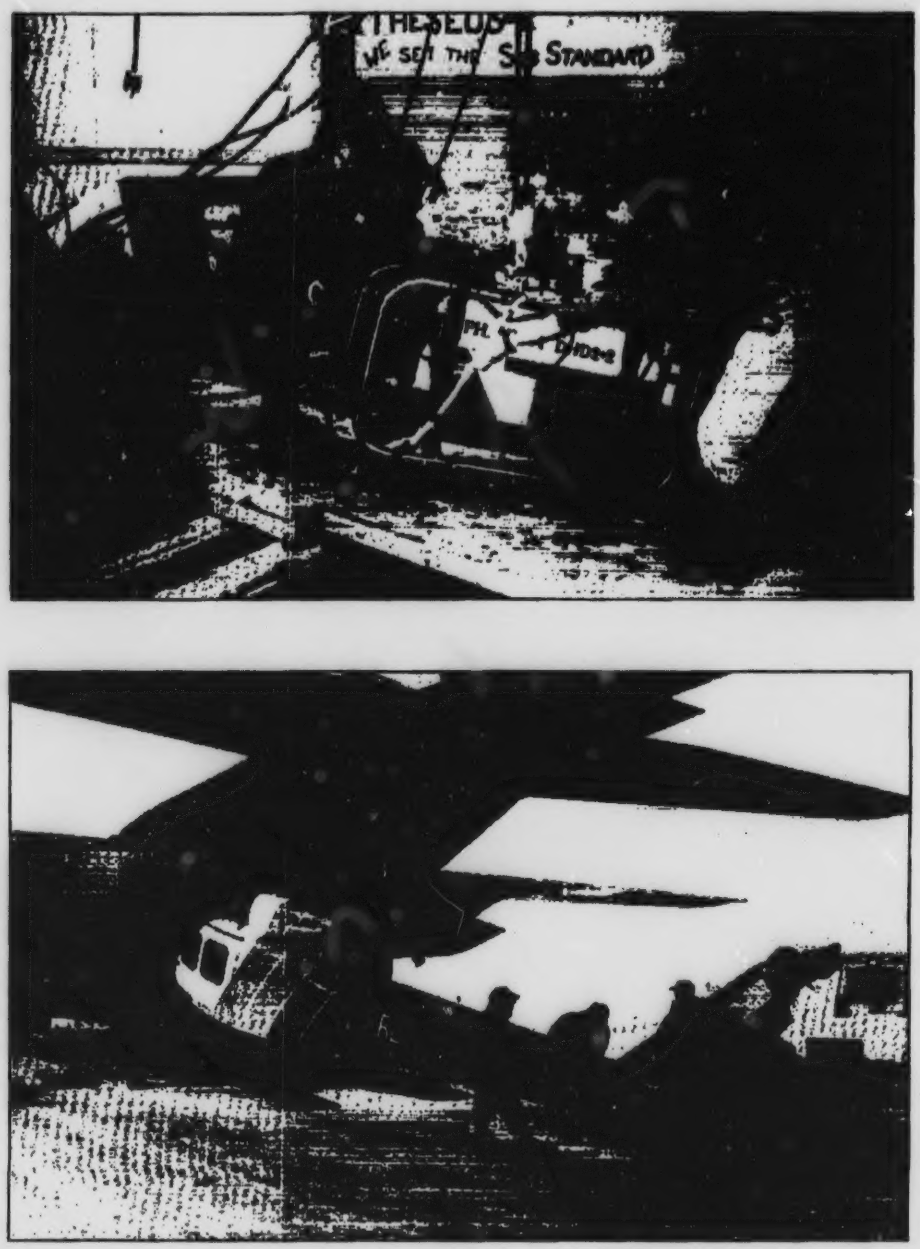
(top) *Theseus* was assembled at Jolliffe Bay in a 65x36-ft custom-made, self-erecting tent. Tudor Davies, the deputy project manager, tests the launching and recovery pool before the immersion of the vehicle. An astounding 30 others also availed themselves of this recreational facility. (bottom) *Theseus* being launched.



Theseus: (top) in the water; (bottom) on the way to deliver the fibre optic cable to the ice-floe above the array.



(top) Barbara Sotirin and Maureen Yeremy await the arrival of *Theseus* at one of the two icecamps north of Alert. The shore cable from *Theseus* is to be brought onto the ice-floe and connected to the array cable. Sufficient slack is introduced into the shore cable to compensate for ice drift during the splicing process, using the procedure shown in the inset—the cable is attached to a sled hauled by a constant tension capstan. (bottom) Jim Kennedy and Ron Verrall at the capstan conducting a test run.



(top) Three times during the two return trips, *Theseus* became confused and settled on the sea floor. A party was then sent out by helicopter to rescue the vehicle. On two of the occasions, the *Phantom* ROV—shown here with Steve Taylor, Dave Hopkin and Jim Milne—attached a recovery line to *Theseus*, which was then raised, reprogrammed and sent on its way. (bottom) After the completion of ICESHELF'96, the chartered helicopter was loaded into a CF Hercules for its trip south.

Electromagnetics

Following the successful demonstrations in 1985 of inboard MAD, a number of countries, including Australia and the UK, purchased CAE AIMS systems. The most impressive order by far was that received in November 1987 from the UK to equip RAF Nimrods and RN Sea King and Lynx helicopters for ASW operations. To place this contract in perspective, at $38-million it was reputed to have equalled the rest of the two-way sales in defence equipment between the two countries for the entire year. This attests to the advanced nature of the system based on the CAE fully automated compensation system and the DREP automated detection algorithm.

In flight, an aircraft is a conductor moving in the earth's magnetic field. Hence motions of the aircraft due to pitch, roll, yaw, acceleration or change in altitude cause changes in the aircraft's induced magnetic field which are picked up by its magnetometer. Compensation systems measure the various motions, compute the induced fields and feed signals of opposite polarity to the sensor to cancel out the aircraft-induced changes. AIMS compensates for sixteen magnetic terms. To keep performance from degrading, it is essential that the sixteen coefficients be updated at regular intervals. In the past this would have been done by flying the aircraft on the four cardinal headings and subjecting it to violent movements in pitch, roll, and yaw. The main problem with this approach was that the violent movements were very stressful to the aircrew, who, in response, tended to avoid updating the compensation to the detriment of system performance. Fortunately, studies conducted by Bradley Nelson demonstrated that the use of considerably less violent manoeuvres actually improves the compensation. In addition, he observed that it was not necessary to fly on all four cardinal headings. These improvements, combined with the high speed of the automatic compensation system, meant that the aircrew could, and most probably would, keep AIMS operating at peak performance with relatively little effort. Bradley then assisted CAE in the development of an algorithm, based on a Kalman filter, to set the compensator's coefficients automatically using the aircraft's normal motions rather than dedicated manoeuvres. This resulted in updates being made to several hundred copies of the company's AIMS software held throughout the world.

The magnetic state of an aircraft is critical to the successful operation of MAD. This is particularly so for helicopters, with their flexible airframes, rotating blades, and machinery in close proximity to the magnetometer. Reducing the effect of such factors on helicopter self noise was the responsibility of Bradley Nelson and Harold Wilson who became very proficient in this area. Although the Gulf War was not an ASW operation, shortly after it commenced, their expertise in diagnosing and correcting problems with the magnetic state of the Sea King was called into play. The CF had decided to send a number of these helicopters to the Gulf and had equipped them with infra-red jammers for missiles. This installation caused gross errors to occur in the their magnetic compasses. Because of the urgency of the situation and being aware of their capabilities, the CF requested that Bradley and Harold immediately proceed to Shearwater to help solve the problem. Once again, the collision light was found to be at the centre of the problem. A solution was quickly devised and instructions sent to Gibraltar for modifying another five Sea Kings that had already sailed on the PROTECTEUR.

Work on improving the magnetic state of the Sea King continued for a number of years, with much of the DREP effort devoted to de-magnetizing *in situ* various rotating components, including the rotor blades. Eventually, background levels were reduced to the point where the performance of helicopter MAD nearly equalled that of fixed wing aircraft, a remarkable achievement. This performance was demonstrated in trials at the AUTEC tracking range in the Bahamas in the spring of 1994. The trials were not without adventure as a Sea King carrying Bradley Nelson made an unplanned landing which required some days to repair. Because of the concentrated effort in electromagnetic quietening of helicopters, Canadian military helicopters were most likely the quietest in the world and this was reflected in the performance of their MAD systems. As it was important to CAE that their other customers extract as much performance as possible from their AIMS systems, Bradley Nelson advised CAE—in 1995—on techniques for reducing the magnetic noise in the RAAF Sea Hawk helicopters, advice which would be generally applicable to all in-board helicopter MAD systems.

In order to be in a position both to predict and optimize MAD performance in areas of operational interest, Bradley Nelson played a key role in the planning, organization and conduct of geomagnetic surveys off Canada's three coasts. The most extensive was that conducted since 1986 under the Polar Margin Aeromagnetic Program (PMAP) using the IAR Convair. By defining DND requirements, participating in the data collection, analyzing the resulting data sets and reporting the results in forms suitable for both the military and geophysical scientific communities, it was possible to achieve DND objectives at a fraction of the total cost. The quality of the data was enhanced considerably by a 27-term aircraft compensation model developed some time earlier in a joint effort by DREP and IAR scientists. The system produced a significant lowering of the aircraft's magnetic background, a particularly important consideration when collecting gradient data using the Convair's wingtip magnetometers.

Throughout the period, military forces conducted training operations in the North. DREP participated in a number of these which involved the Auroras. By taking advantage of the presence of these aircraft and the Convair, it was possible to survey systematically vast areas of the ocean floor off the northern coast of Ellesmere Island. The experience and techniques developed in these surveys led DREP to participate in Project Ootjoolik, an aeromagnetic survey using CF aircraft to help locate one of Sir John Franklin's lost ships. DREP contributed by defining the coordinates of the most likely sites, using magnetic anomaly data combined with what was known of the characteristics of the ship and its machinery. The project involved extensive co-operation with the Maritime Air Group (MAG), MP&EU, IAR and other government and non-government agencies. Regrettably, a subsequent diving operation concentrating on the ten most likely hot-spots failed to find any trace of the lost ship.

The discovery of Josephson Junctions and SQUIDs in the 1960s had shown that it should be possible to measure the gradient of the magnetic field with a small (<40 cm) superconducting sensor. It was already well known that if the tensor gradient of a target could be measured, its position could be determined precisely, a feature that total-field MAD systems could not hope to emulate. This was such a compelling attraction that it became expedient to overlook the two obvious difficulties with these systems: they had to be flown in a towed 'bird', and they required liquid helium, which few military bases have any experience with. So, in the 1970s, several naval laboratories around the world set to work to develop an operational system. By the mid-1980s, all had become wiser as one noise source after another appeared in moving SQUID sensors.

Harold Wilson spent the next few years using the Rocky Point installation to measure the response of the SQUID system to temperature changes, pressure fluctuations, vibrations, tilts, electronic setup, and trapped and applied magnetic fields. The measurements were done in the normal configuration with the system sensitive to the external field and in the 'shielded' configuration where a superconducting shield isolates the SQUID from the surrounding magnetic field. CTF installed new SQUIDs twice: once, they replaced the original point-contact SQUIDs with another set of point contact SQUIDs but with an all-niobium design and, in 1990, thin-film RF

SQUIDs were installed.

The tests showed that there were so many sources of noise in moving systems that it was surprising that the 1983 trial had produced results as good as they were. And yet, DREP found nothing fundamental to limit the gradiometer sensitivity. It just seemed that you had to be aware of the problems and design the system and test components before installation to make sure that they were under control. This was the 'good news' arising out of several years of measuring system failures.

In 1986, CTF and DREP realized that they would have to progress to thin-film DC-SQUID technology from the old point-contact Josephson Junction/bulk-niobium SQUID technology that CTF and their competitors had been using since the 1970s. Therefore, DREP and the Defence Industrial Research program funded CTF to develop thin-film niobium Josephson Junctions and the associated thin-film patterning technology. This project was a real eye-opener for Roy Erickson and Harold Wilson who monitored the contract. The technical literature in those days gave the impression that niobium films were simple: 'just' evaporate the layers, oxidize where required and you get Josephson Junctions. It soon became evident that the literature never mentioned the small details of contaminants, thin-film tension, thin-film lithography, etc., that made the whole process very difficult. Fortunately, DND and CTF persevered, and today, CTF's DC SQUIDs are at the centre of their biomagnetometer technology and CTF is probably the leading supplier of SQUIDs in the world, because each biomagnetometer uses up to 150 SQUIDs. It is worth noting that CTF would not be exporting many millions of dollars of super-conducting magnetometers each year had they not received support from DREP through the late 1970s and 1980s, and that DND's connection with CTF would likely never have happened without a CRAD research facility on the West Coast.

In 1988, Roy Erickson decided to start work on a light-weight, low-power SQUID electronics package which could be used in airborne trials. CTF's SQUID electronics, which were used for the noise tests at Rocky Point and in the barge trial, were much too bulky and power-hungry for an airborne trial. The concept was simple: instead of designing a fancy second-order analog feedback loop, the new electronics would consist of an analogue-to-digital converter, a signal processing microcomputer and a digital-to-analogue converter to drive the feedback signal to the SQUID. The SQUID signals would be transmitted on an optical fibre to a data-acquisition computer. The system was developed and made operational by Roy Erickson, Brian Dunstan and George Schattschneider of DREP and Tom Foxall of Signum Systems in a series of research contracts. In 1995, the digital electronics were adapted for use with DC SQUIDs.

DREP funded research on thin films of high transition temperature (high-T_C) superconductors at CTF in two research contracts from 1987 to 1990. CTF demonstrated that they could make thin films of yttrium and thallium, and could fabricate SQUIDs, but the contracts also showed that DREP and CTF did not have the resources required to develop a working high-T_C gradiometer in the foreseeable future. In 1990, Harold Wilson decided that DREP would suspend funding of high-T_C research, the hope being that it could return to this subject in the late 1990s when solutions had been found to the problems of SQUID fabrication in the new materials. CTF continued in high-T_C research for another 5 years with funding from Industry Canada and Furukawa Electric of Japan.

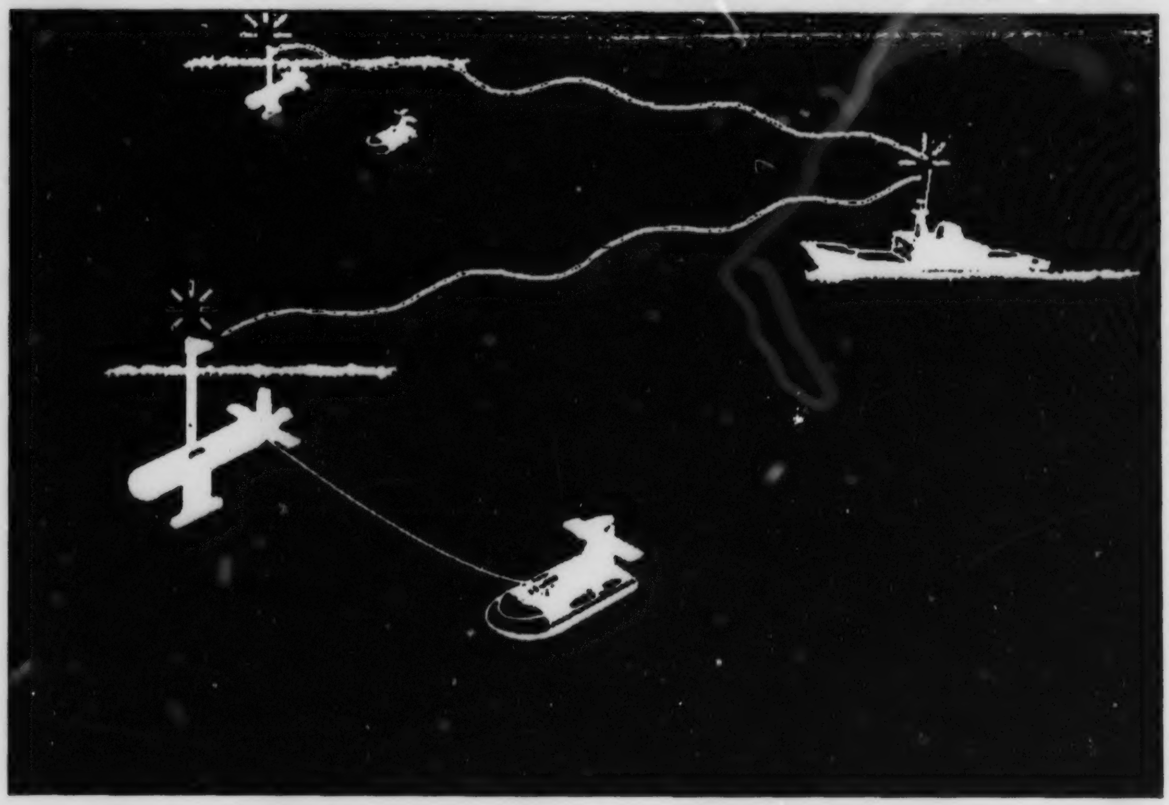
Having concluded that motion noise was sufficiently well understood, it was decided to redirect efforts towards building a low-motion-noise 'conventional' niobium low-T_C gradiometer. Accordingly, DREP placed a contract with CTF for a design study for a new SQUID gradiometer. In the contract, CTF demonstrated feasible approaches to solving all of the motion-noise problems that DREP identified, and in late 1993 work was initiated on the development of a new vertical gradiometer.

In preparation for flight trials, a towbody for the gradiometer was developed and flown at CFB Cold Lake. This seemed a simple task, but it turned out that nobody had designed a towbody which was essentially a cylinder in a cross flow. Dave Hopkin did the aerodynamics, Rick Religa designed and built the towbody and Brian Dunstan adapted Tom Foxall's battery-powered SQUID data acquisition system so that data from motion sensors mounted in the towbody could be recorded. The first flight trial, at Cold Lake, in May 1992, was a failure: at 60 knots a severe pitching instability appeared in the towbody. After analysis and some towbody modifications, a second flight trial was conducted in November 1993. Everything went smoothly and showed that the random accelerations on the towbody were considerably less than anticipated at speeds up to 80 knots. This proved to be valuable information that was used later in the design of the new gradiometer, now scheduled for flight testing in mid-1998 by an industry-EDRD partnership.

Gradiometer towed body trials at Cold Lake

Mine Countermeasures

The focus continued to be on the development of route surveying and minehunting technology[61] and the reduction of ship-radiated electromagnetic signals[62] to make the fleet less susceptible to mines. As the program evolved it was impacted heavily by a decision of the CF to build a Maritime Coastal Defence Vessel (MCDV) and to include mine hunting as one of its roles. As the MCDV was to be steel hulled, this placed extraordinary demands on the minehunting technology base. Clearly, any serious approach to minehunting from such a platform demanded that it be conducted remotely—the more so the better. Based on this requirement and guided by DREP's previous experience and ongoing research, the preferred approach was to hunt for mines acoustically using a sidescan sonar towed from a Remotely Operated Vehicle (ROV)—the vehicle might well be pre-programmed and operate autonomously—with the information telemetered back to the accompanying MCDV for onboard analysis. As it was expected that in many potential operating areas, the bottom might be littered with many mine-like objects, it would be essential to simplify the problem. It was therefore considered desirable to survey the area in advance. In the interest of efficiency, the preliminary route surveying



ROV-based minehunting system

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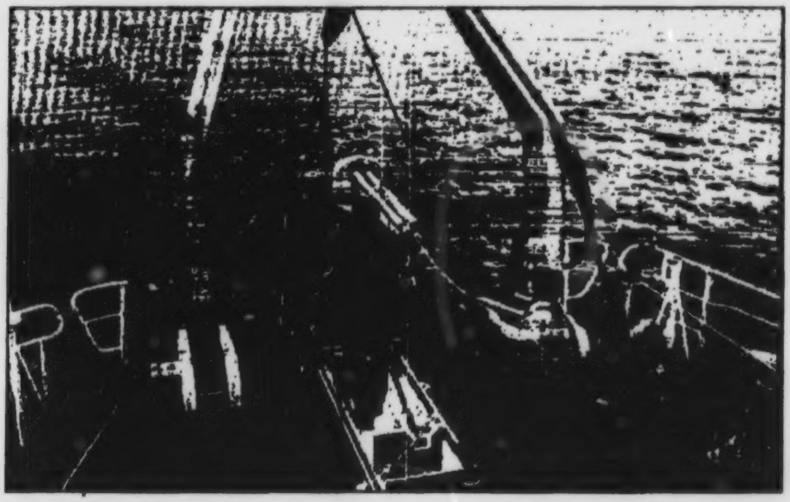
[61] The minehunting effort was under the direction of Ron Kuwahara who played a leading role in the associated systems studies and interactions with TTCP countries and the CF. The scientist primarily responsible for sonar platforms and their relation to towing vehicles was Jon Preston, for navigation was Bill Vogel and for signal and image processing was Roland Poeckert.

[62] Peter Holtham had the primary responsibility for the work on ship quietening.

would be carried out from surface ships towing sidescan sonars, ideally the MCDVs as they would have the required data processing and navigation equipment already on board. The problem would then be reduced to detecting and reporting only on minelike objects that appeared in the area since the last survey. The problem is far from trivial as both mines and many of the objects cluttering the bottom look acoustically quite different when viewed from different angles. Interleaving data from different surveys and relating them to those gathered during the minehunt also presents significant challenges in navigation, towed body positioning, data handling and signal processing.

Previously, state-of-the-art minehunting systems required very expensive, low acoustic- and magnetic-signature minehunting vessels equipped with costly minehunting sonars. DREP focussed on examining current commercial technology to see if a system could be developed which would meet the requirement at an affordable price. Suitable technology was available locally in image processing (MDA), sonars (Simrad Mesotech), navigation (OSL), and ROVs (ISER). It was adapted to MCM through a number of research contracts. Later, companies who had benefitted from the DREP research program contributed to the winning MDA proposal to supply a route surveying system for the MCDVs, the concept adopted being essentially that pioneered by DREP. A sonar image data base collected by DREP using military and research vessels provided the foundation on which to build the development process. Advantage was also taken of the tremendous advances in computing power then taking place, without which, this project, computer intensive indeed,[63] could not have hoped to succeed.



Sidescan sonar being launched for an MCM survey by Bob Chappell, Sonia Latchman and Jon Preston

Somehow the feeling had arisen in military circles that DREP's success in detecting mines laid on the bottom might have had less to do with advanced technology than with the benign conditions in Esquimalt Harbour and its approaches. "Find mines off Halifax, that would be a challenge worthy of your steel." And so, in 1987, the DREP technical staff and equipment got to participate in a major minehunting exercise in the approaches to Halifax Harbour. Environmental features of the sea-floor were examined and developments in navigation and tow-fish attitude and positioning were tested. The trial demonstrated the feasibility of minehunting on a difficult seabed topography, but clearly showed the need for accurate and well positioned route survey data. The area was resurveyed in September 1993—using the more refined techniques that had been developed in the interim—to look at seabed stability over time and sea clutter density. These exercises had done much to convince the Navy of the validity of the DREP approach to minehunting and to solidify the link between the scientists involved and CF operational and engineering units, a relationship which survived intact the formal closing of DREP. In recognition of the growing interdependence of the DND civilian and military staff concerned with minehunting, the CF supplied a military position[64] to the MCM group which helped feed and support this growing relationship. The principal area of ongoing interaction was the MCDV; DREP contributed actively to defining the requirements for route surveying and minehunting and the technical approach to be followed in meeting the requirements. Thus the MCDV provided both a clear focus for the DREP minehunting program and a customer well motivated to take an interest in the program and to follow developments, an ideal situation for all concerned.[65]

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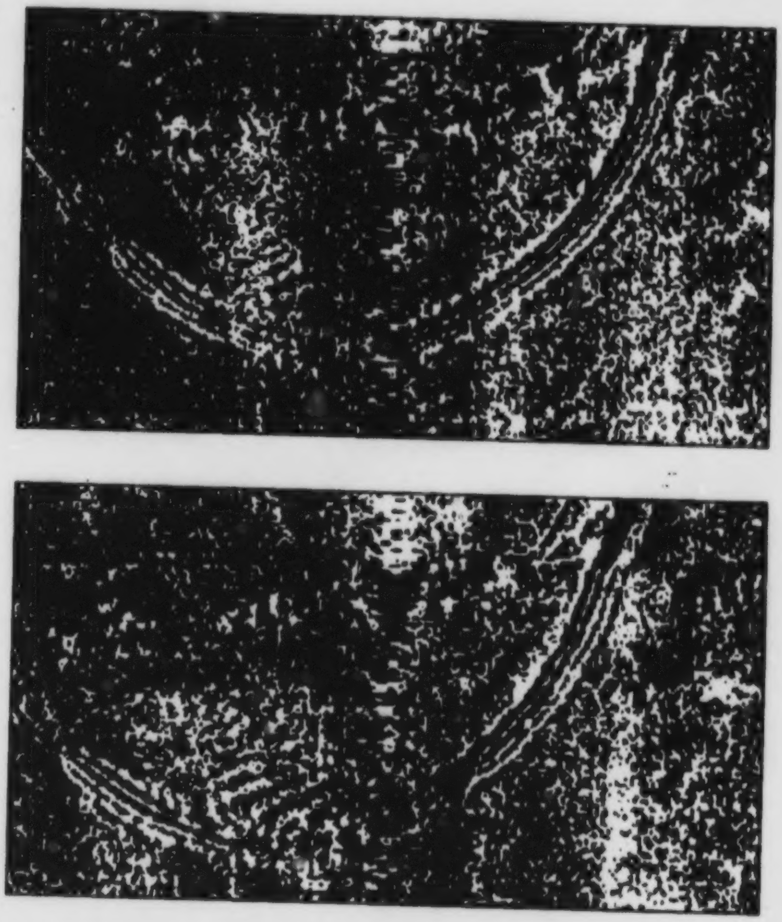
[63] At a briefing in early 1996, one of the contractors brought out this point by claiming that there was more computing power in one MCDV than in all 12 of the Navy's patrol frigates combined. Whether or not this was literally true, it certainly caught the spirit of the operation.



(top) Sidescan sonar record showing scour marks on the bottom of Halifax Harbour approaches. (bottom) Mine added later in the exercise is shown at bottom left.

In 1986, an extensive field trial involving ARE Portland and DREP—with observers from the US and NZ—was conducted in Esquimalt Harbour to evaluate the MCM possibilities of four commercial sidescan sonars. A large array of minelike targets was deployed, leading to a database of sonar records suitable for determining sonar performance and target positioning accuracy. Techniques for mapping or geocoding of the sonar images were developed under contract. Work was also initiated at this time on the simulation of cable towed body dynamics and on a servo controlled winch for keeping the sidescan sonar at a constant height above the bottom. Some time earlier, OSL had developed a navigation system for the precise positioning of ships and oil-drilling equipment. The company now employed its expertise to develop a precise integrated navigation system (PINS) to provide state-of-the-art positioning for the sonar towship.

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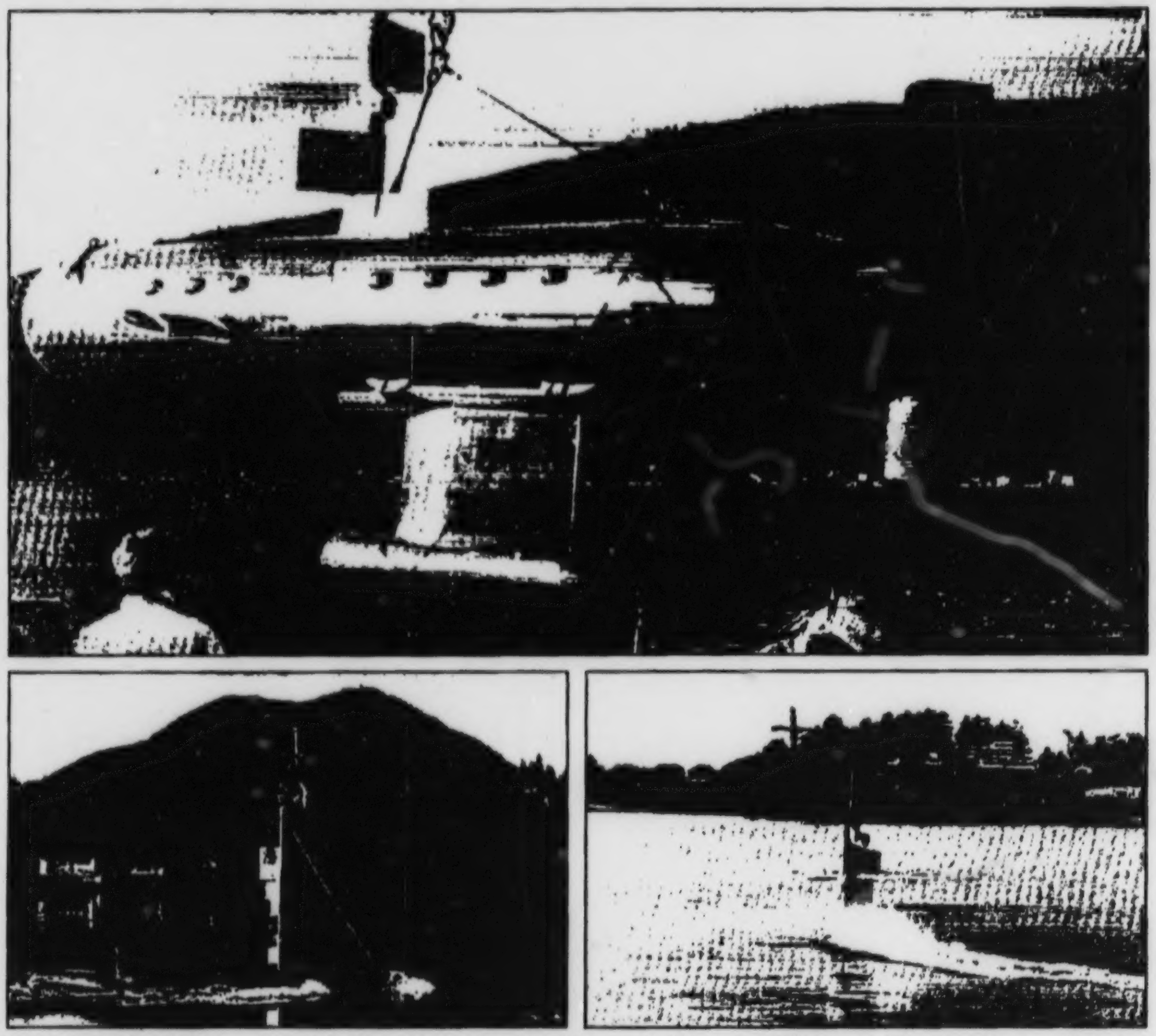
[64] The first incumbent was LCdr R.F. (Bob) Gwalchmai who arrived in mid-1988. On his departure two years later, the position was filled by LCdr P.S. (Paul) LeGallais, formerly the commanding officer of FDU(P) and, after his retirement from the CF, DREP's last Research Ship Coordinator. Subsequent holders of the MCM position were LCdr Bill Laing and Lt(N) Mike Meakin.

[65] This of course would be the ideal situation for all projects; however, the MCDV is one of the select few where the flow from concept to production proceeded with apparent ease. In other cases—those involving submarines and helicopters spring to mind—the major vehicle which provides the focus never reached the production stage.

In 1988, sea trials were carried out in various sea states to investigate the interaction between towing vehicles—ENDEAVOUR and the ISE *Dolphin*[66]—and towing platforms. Taking advantage of the lessons learned in the 1987-exercise, a neutrally buoyant towfish was introduced into the trials, resulting in much improvement in the stability of the sonar images.



The ISE *Dolphin* - (top) being launched - (lower left) travelling on the surface – (lower right) semi-submerged

In route surveying, where the data from a number of trials may have to be superimposed, it is essential that a common geographical reference be used. Techniques for doing this, called geocoding, had been developed by MDA for satellite imagery. The company was contracted to apply its expertise to route surveying. Although a program for full sonar beam modelling and precise geocoding was quickly developed, it required extensive refinements before "geocoded" sonar maps could be produced.

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[66] *Dolphin* is a semi-submersible, which drastically reduces its motion in open seas compared to surface platforms of comparable size.

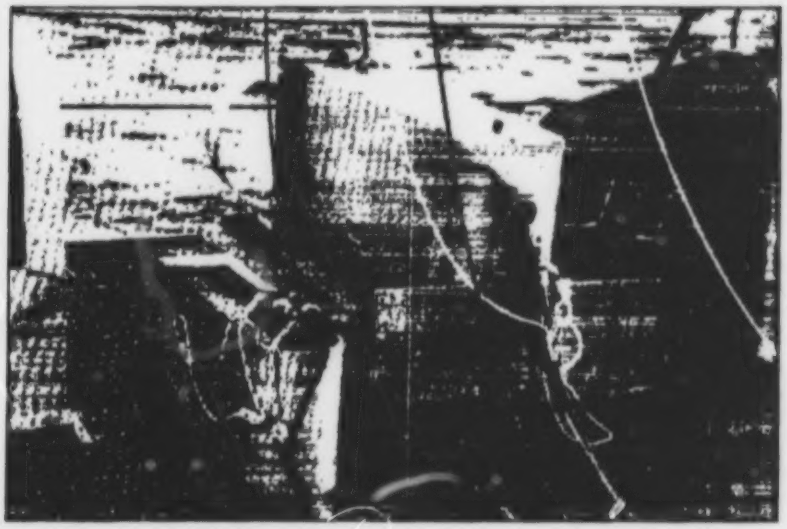
To assist the CF in their planning for the MCDV, a prefeasibility study was conducted on a Remote Controlled Minehunting System (RCMHS). The report considered the requirements and recommended a vehicle towed by an autonomous drone as the best choice and one which was compatible with Canadian industrial capability. The effectiveness of the various minehunting concepts used in the study were compared using the UK-developed Minefield Clearance Simulator.

In 1989, emphasis was placed on building a route survey system which could produce and compare geocoded sidescan images of the sea-bed and on commencing the research required for the development of a remotely controlled minehunting system. A contract was let to the University of Victoria to study the problem of improving towfish position and attitude estimates using navigation and attitude data; the information derived from this contract was later used for software corrections to the sonar images. Late in the year, sea trials were conducted off Halifax to measure the stability of the ISE *Dolphin* in high sea states. In signal processing, a geocoding algorithm and a new mosaicing technique were implemented by MDA for the DREP Sonar Image Processing System (SIPS) and applied to a 1x1-km portion of the seabed at the entrance to Halifax Harbour. BCS commenced work on an image warping algorithm to improve the superposition of images using identifiable features on the bottom as tie points.

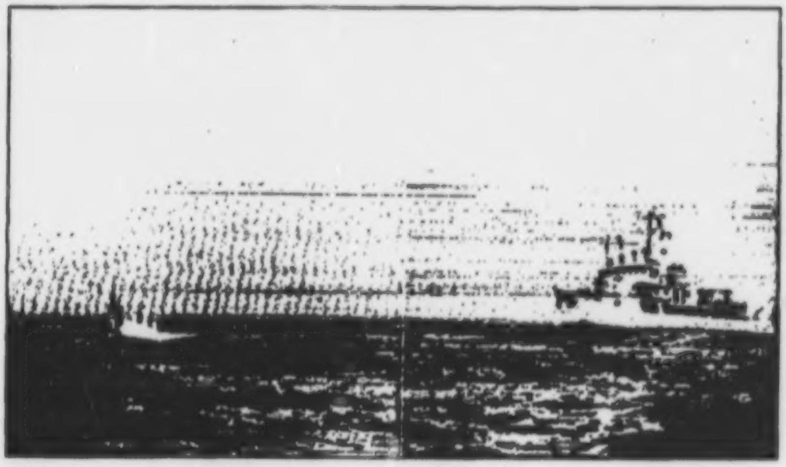
In 1990, emphasis continued on building a route surveying system. Problems relating to navigation were addressed. The relative accuracies of a number of electronic navigation systems were measured in the entrance to Halifax Harbour. OSL developed a version of PINS which could include radar overlays and use polarized radar reflectors in place of microwave transponder reference stations, an approach which considerably simplified minehunting in nearshore areas. A geocoding algorithm was used in the analysis of motion-compensated images of the 1988 and 1989 sonar data, an operation facilitated by an upgrade to the SIPS workstation which provided a "blink" and "roam" capability. BCS continued the development of algorithms to provide high-speed warping of the sonar imagery. Research continued on the use of ROVs in minehunting, both through simulation studies and experimental investigations. A limited swim-ahead capability was obtained by incorporating thrusters, winglets and a thin wire tether for control and data transmission into *Manta*, an elegant, bat-shaped towed underwater vehicle produced by SEAI, a local marine engineering company. Encouraging results were obtained in a trial carried out at the Nanoose Range in March 1990. *Manta* was towed into position by ENDEAVOUR and the tow cable disconnected. *Manta* then achieved a separation from the ship of 1,000 m under its own power.

In mid-1990 Iraq invaded Kuwait, an event which exerted a considerable impact on the DREP MCM program. At the time, Ron Kuwahara was in Ottawa attending a meeting on the MCDV. At the request of LCdr Jim Hewitt of MARCOM, he was immediately diverted to Halifax where, for the next several weeks, he led an investigation of the feasibility of using a commercial fish-finding sonar in mine avoidance. The study team, which included DREA's experts in active sonar and DREP's in navigation, conducted systems studies, and associated field trials in Bedford Basin. The preliminary results were promising and the sonars were immediately modified and then fitted to the ships—TERRA NOVA, ATHABASKAN and PROTECTEUR—being sent to the Gulf. Following their departure, more detailed technical and operational testing was conducted using a similar sonar installed on NIPIGON. As a result of the various investigations the study team was also able to provide the task force with a sonar prediction capability and an MCM oceanographic atlas of the threat zone.

Effort then refocussed on route surveying; a new neutrally buoyant towfish was designed to incorporate more attitude sensors and a new dual-frequency, high-resolution sidescan sonar was built by Mesotech. A major set of sea trials was conducted in the spring of 1991 to test both the subsystems and the fully integrated system. These trials culminated with a route surveying exercise in the Strait of Juan de Fuca off Esquimalt. In July, a joint trial—sponsored by GTP-13—conducted in Bigbury Bay in the UK, further demonstrated the merit of multi-beam sidescan sonar. In late 1991, a well supported sea trial was conducted off Ucluelet to compare the stability of a tow-fish coupled to the *Dolphin* with that of identical units towed from a number of much larger surface ships. In a given sea state, *Dolphin's* performance was comparable in most respects to that of ENDEAVOUR, a vessel of 100 times the weight.



Two-part tow with neutrally buoyant towfish designed to improve the accuracy of sidescan sonar imaging



Towfish stability trials off Ucluelet with *Dolphin* controlled from CSS Vector

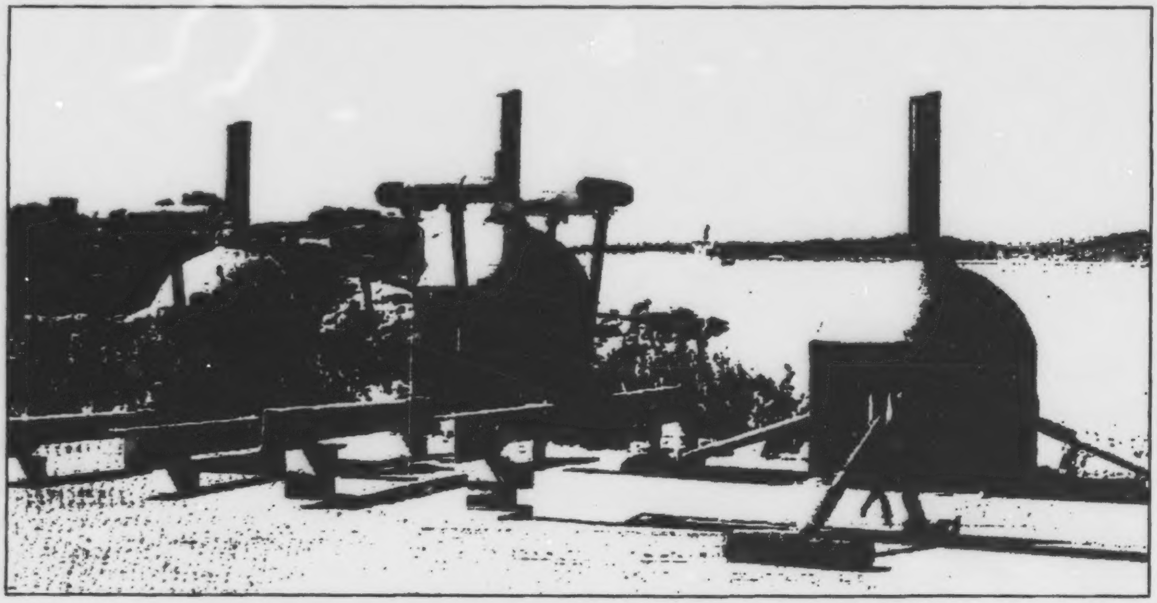
By 1992, the system had developed to the point where the position accuracy of objects on the bottom was from 5 to 10 meters, close enough for control point matching and mosaicing. It was then used to collect samples of the seabed off Esquimalt, and at other locations in the Strait of Juan de Fuca, to generate a route surveying library of composite images for use with the SIPS geocoding and mosaicing algorithms. The following year, the library was extended by a similar survey conducted from HMCS MORESBY in the approaches to Halifax Harbour.

The viability of the DREP concept of route surveying having been demonstrated, it was officially adopted for the MCDV during a 1993 design review meeting. From then on research concentrated on developing and improving the navigation, towfish positioning, image warping and associated algorithms required to support the program.

Staff conducting sidescan sonar trials – (top) back, Roy Erickson, Ron Kuwahara, Dave Hopkin, Bob Chappell, Bill Vogel – front, Art Fitchett, Albert Labrie, Kurt Lane –(bottom) Jon Preston, Mike Meakin, Wendy Don, Roland Poeckert, Mark Rowsome, Ken Ashcroft, Terry Miller

Developments in the measurement, identification and eradication of low-frequency ship-generated electromagnetic signals continued. Some of the technology was transferred to industry where MILSPEC versions of equipment to suppress the radiation were developed. Testing and evaluation of this equipment often took place in an international setting, thus allowing DREP to profit from the experiences of our allies. This co-operation also considerably enhanced the opportunities for Canadian contractors to make foreign sales. Sensors and hardware were designed and installed in the entrances to Esquimalt and Halifax Harbours for measuring ship radiated electromagnetic signals and evaluating countermeasures. This provided the CF with the capability for monitoring on a regular basis the susceptibility of their ships to mines.

Davis Engineering produced a MILSPEC version of the shaft-grounding system which was tested by DREP on two US warships in 1988. A CF operational evaluation (OPVAL) was scheduled for the spring of 1990 to determine the suitability of the system for future fitment to CF ships. However, because of the rapidly changing world conditions, the evaluation was postponed a year and the active grounding systems to be used in the trials were installed on the ships going to the Gulf. An identical situation presented itself the following year when the OPVAL was again postponed and the replacement units fitted on the second wave of ships going to the Gulf. Fortunately, both times, enough units were available either from Davis Engineering or the DREP research program to meet the requirement. A parallel situation existed for a second countermeasure, developed to eliminate the electromagnetic signals radiated by currents flowing in ships' cathodic protection systems. This countermeasure, an Active Cathodic Protection filter,[67] had been developed in 1989 and a contract let to Davis Engineering to produce a MILSPEC version. Again, a sufficient number of units was available to supply the ships in the Gulf. The timing of an earlier decision to install state-of-the-art electromagnetic sensors in both Halifax



EM sensors about to be installed in Esquimalt Harbour

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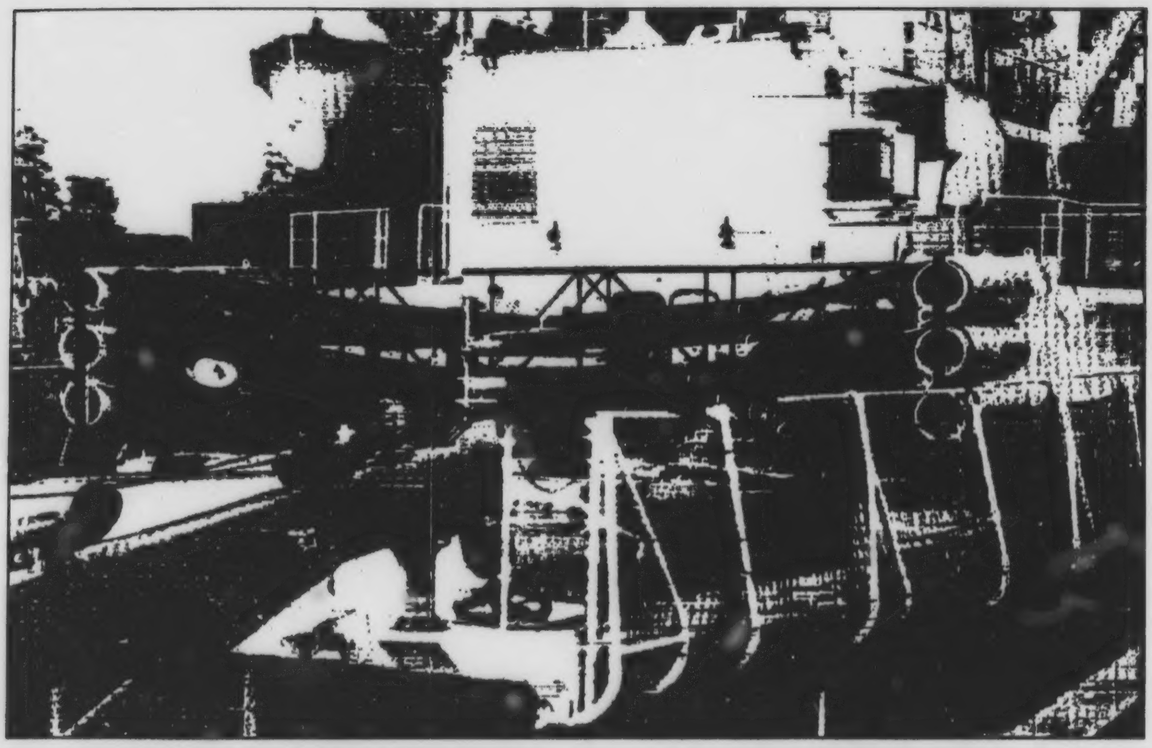
[67] The filter development was a co-operative effort of Peter Holtham in Mine Countermeasures, George Schattschneider in Applied Technology and Jim Moores in Materials Technology. In 1994, the latter received the Public Service Commission's prestigious "Award for Excellence," in part, in recognition of his contribution to this development.

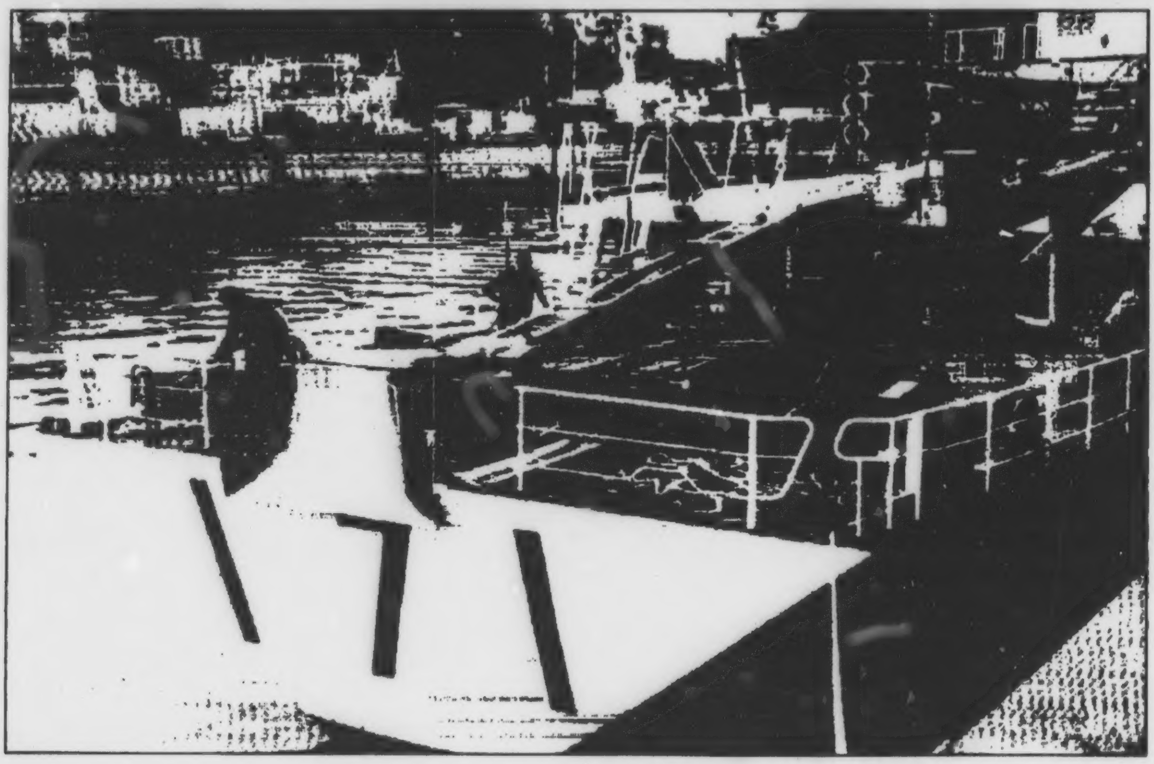
and Esquimalt Harbours for measuring ship radiated signals was equally fortunate. The first sensors had been installed in Halifax Harbour in 1989 and so were available to measure the magnetic state of the Gulf-bound ships and the effectiveness of their countermeasures. The measurements were made by DREP staff, as it was not until 1992 that the shore electronics and procedures had been developed to the point where operation by non-scientists became feasible. The sensors for the range in Esquimalt Harbour were installed in 1991. Their first job was the ranging of RESTIGOUCHE after she was fitted out with electromagnetic countermeasures and before her departure for the Gulf. It was later decided that the measurements and testing related to the various Gulf deployments were in effect an OPVAL and nothing more was required. The decision to have industry take over the development of the shaft-grounding units proved to be inspired; by mid-1997, sales by Davis Engineering were to Canada 24, the US 47, France 1 and the UK 9—with more units being constructed in the UK under licence. Negotiations for sales were also being conducted with several other countries including Australia, South Korea, Spain and Turkey.

The technologies required to determine ship vulnerability to mines and the effectiveness of underwater electromagnetic surveillance systems are essentially identical. Both areas, in addition to that of ship quietening, were the responsibility of Peter Holtham and his associates working out of the MCM Group. Over time, the emphasis fluctuated between ship vulnerability and surveillance depending on the strategic threat or perceived opportunity, the immediate requirements of the military customer and the opportunity to leverage effort through co-operation with our allies, primarily the US. The results were regularly supplied to the CF ship and submarine acquisition programs to permit the assessment of the vulnerability of the various candidates to hostile action. The measurement program consisted of dedicated field trials to measure the signals radiated by selected targets and of long-term studies of the ambient background in which targets were to be detected. In the 1980s, effort was concentrated on the Arctic, in the 1990s, on the Strait of Juan de Fuca. In both areas there was strong co-operation with US scientists and operational units. A significant contribution to these activities was the DREP expertise—acquired over several decades—in the design and construction of advanced electromagnetic sensors.

Activity in the Arctic peaked in 1988 and 1989 with major field trials on the ice north of Alaska and the setting up of two additional field stations in the Canadian Archipelago—bringing the total to four—for studying long-term variations in the ambient background. In 1990, data from these stations were telemetered back to the laboratory in Esquimalt via satellite. The next year the Gulf War resulted in a redirection of the satellite, thus severing the link and effectively terminating the work in the North. Even if this had not happened, the program would very probably have been wound down as it was at this time that an invitation was received from the US asking DREP to participate in an extensive measurement program in the Strait of Juan de Fuca.

Following the acceptance of the invitation, an extensive crash research program was carried out to develop extremely low noise dc-electric field sensors, as well as to improve the sensitivity of ac field measurement systems. Contracts were then let to industry to produce the sensors. Two large field operations were mounted during May and September 1992 to deploy the sensors at the measurement site in Neah Bay, Washington. Trials then proceeded with the US to measure the signatures of a variety of ships passing over the array. Long-term recordings of the ambient noise background were also made at the site to provide a data base for the development of signal processing techniques for ambient field removal. This very successful example of international co-operative research was completed in January 1995.





(top) EM arrays stacked on ENDEAVOUR, for installation in Neah Bay. (bottom) Launching system for EM arrays.

Peter Holtham (at rail) and Doug Schneider (to his right) assisted by crew members of CFAV ENDEAVOUR install cables in Neah Bay

Materials Technology

Day-to-day support to the CF and longer term research continued with the bulk of the effort being expended approximately equally on problems affecting the sea and air elements. Extensive leveraging of the in-house resources through contracting with industry and participating in international research activities remained an important feature of the program.

In air materials, problems relating to operational equipment were addressed in non-destructive evaluation, composite materials, advanced alloys, paints and paint removal and cleaning, corrosion prevention, ceramics and adhesives. Throughout the period, work was conducted on advanced composite materials, their repair, long term durability and damage tolerance. As the average age of the CF aircraft continued to increase, more effort was directed at the detection and characterization of corrosion and towards the investigation of the properties of new materials, such as aluminum-lithium and other advanced aircraft structural alloys which would be used in new equipment and for repair. Work on the environmental degradation of polymetric materials, including new materials being proposed for aircraft use, became of increasing concern. Coatings research focussed on the development and evaluation of environmentally safe coatings and on non-traditional methods for paint removal.

The air materials program was supported and indeed shaped by participation in a wide range of international activities. DREP supplied the Canadian National Leaders for TTCP Panels PTP 1 (Metals), PTP 3 (Organic Materials), PTP 4 (Systems), and PTP 5 (NDE) and also supported through membership, PAG 9 (Composite Supportability and Maintainability). It also provided the member for the Advisory Group in Aircraft Research and Development (AGARD) Structures and Materials Panel and the co-ordinator for Franco-Canadian Accord activities on composite repair.

Todd Garrett presents TTCP achievement award to Bill Sturrock for his contribution to collaborative studies on impact damage to composites

The graphite-epoxy composite used extensively in the CF-18 aircraft represented a generation—vintage 1970—of brittle matrix material characterized by low interlaminar fracture toughness. Non-visible defects develop which, even under normal operations, may experience fatigue-induced growth. Under compressive loading, these defects might result in localized buckling and catastrophic failure if they exceed a critical size. As little was known or documented about the origin and growth of such defects, aircraft users adopted a very conservative view of critical size, resulting in unnecessary repairs, lengthy downtime and excessive maintenance costs. As the CF-18 aged, these considerations became of increasing concern. Two aspects of the problem dominated the research program at DREP, the evaluation of the delaminations which take place in composites used in aircraft, and the repair of such delaminations.[68] As a result of the DREP studies, it became possible to raise the limit on allowable delamination size by a factor of four, thereby avoiding in many cases the need for repair. Also

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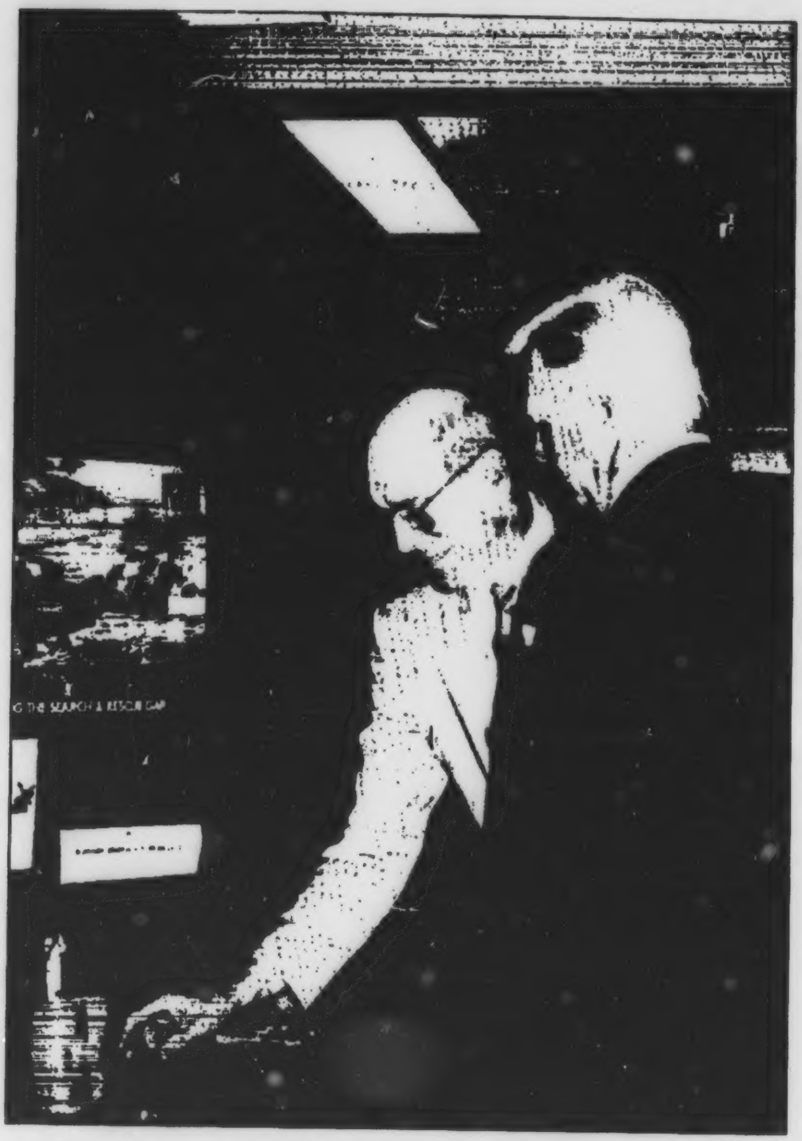
[68] This work was the responsibility of Alan Russell and, until his posting to CRAD/HQ in February 1991, Ken Street. On the creation of the Esquimalt Defence Research Detachment in April 1995, Dr Street became its Director.


G THE SEARCH & RESCUE GAP

Frank Peters outlining DREP research related to the potential purchase of a new helicopter to the Minister of National Defence, Dr Siddon

investigated was the strength degradation due to over-heating of the graphite-epoxy of the CF-18, a consideration which arose in 1986 during the CRV7 air-to-ground rocket clearance trials at Cold Lake. Composites, because of their high strength and low weight, were becoming more common in weapons systems. It was considered that there would be a new generation of thermoplastic matrix composites employed in the New Ship Aircraft. In the early 1990s, work was initiated on the types of composites likely to be used in the construction of this aircraft.

In a war scenario, the overall effectiveness of aircraft squadrons depends on the capability of support facilities. In the CF, some expertise existed for the repair of metallic structures but little for composite structures such as the critical CF-18 wing skins. The program therefore addressed the problem of bolting patches to composite wing skins having holes up to 8 inches in diameter. As increased use of adhesive bonded joints are employed in both aircraft manufacture and repair, the problem of developing improved adhesives and techniques for applying them in the field was also addressed.[69] This led to the development of epoxy adhesives with special additives for reducing the sensitivity to surface preparation, so that more rapid repairs could be made. These superior adhesives received international recognition as a result of co-operative evaluations and industrial trials, including a lightweight bridging project undertaken by the US Army, the CF damage repair program, a Hughes Aircraft program to bond items in the Space Shuttle, a US National Research Program for patch repair and a Martin Marietta program for low-temperature repair of military equipment. In co-ordination with the adhesive formulations, a computer based portable temperature controller was developed which permitted permanent repairs to be implemented in the field. An adhesive injection technique for repairing delaminated graphite-epoxy composite material of the type used in the CF-18 was also developed in co-operation with the CF and an industrial contractor. It worked very well, fully restoring the properties of the damaged graphite-epoxy material and promising significant cost savings through reduced aircraft down time and lower life cycle costs. Requests to evaluate the material were received from major aircraft companies in the US and UK and by laboratories in Australia and France.

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[69] Greg Luoma was responsible for research on adhesives until his departure for a Section Head position at DRES in mid-1992.

In co-operation with DREP, signal processing and imaging software for the ultrasonic testing of organic composites was developed by BCS. The software, used in conjunction with an automated ultrasonic scanner, was able to characterize accurately small delamination defects in the wing skin of the CF-18 which had been incorrectly estimated to be much larger using a hand held scanner. The software also proved to be effective in examining scratches in the aluminum dorsal longerons of the aircraft. The software has been sold commercially to both Boeing and British Aerospace and has been used in conjunction with laser ultrasonic development work, a subject of interest to both the CF and the USAF.

Robotic system ultrasonic examination of CF-18 horizontal stabilator

DREP's historic coatings research and development activities had been exceedingly important to the maritime element of the CF. This expertise was now being increasingly applied to problems affecting the air element. Cleaning surfaces using ice-blasting proved to be of particular interest as it was capable of removing paint from organic structural composites without causing undesirable subsurface damage. A number of small portable units developed by a contractor have been sold to the aircraft industry. In addition, units have been used successfully to clean buildings and to decontaminate radioactive material. They are also being used by auto manufacturers to deburr machined transmission parts.

Work on engine health monitoring continued until 1992. The continuous advancement in engine and gear-box design, combined with the use of finer filter systems, had made obsolete traditional methods, such as SOAP and ferrography. Hence the problem was to develop engine health monitoring methods which were usable in the field for new equipment and to develop on-line methods for detecting debris in oil-wetted machinery. Progress on the use of filter debris analysis (FDA) was extensive. FDA for both the Sea King main gear boxes and Buffalo engines was completed and the methodology transferred to Base personnel at Shearwater and Trenton. Information was also provided to a number of commercial firms who wished to adapt the technology to condition monitoring of heavy land equipment. The Ferroscan[70] on-line ferromagnetic monitor was also successfully transferred to industry, through a subsidiary of Atomic Energy of Canada. By 1989, the product had been extensively evaluated by industry and the first sales made to TransCanada Pipelines.

The marine materials program continued its direct support to MARPAC by solving problems arising on a daily basis in areas involving failure analysis, oil analysis, engine health monitoring, corrosion engineering, paint technology and nondestructive evaluation. The level of requests addressed remained high, for example, 638 from MARPAC and 30 from other government departments in 1992. The technology base to support this activity was developed and maintained either through research conducted in-house or contracted out to industry. The principal areas investigated at this time were: new paint systems including anti-fouling coatings, primers, and low volatile organic compound coatings, with particular attention paid to environmental concerns; paint removal methods; sea water corrosion studies on navy materials and electrochemical techniques for evaluating such corrosion; fatigue and dynamic fracture characteristics of ships' steels, including those presently used on the CPF; environmental degradation of organic materials including polymers used in marine applications; those aspects of composite materials that were limiting their wider use in marine platforms and systems, including long-term durability and EM shielding problems; and ceramic coatings for heat and corrosion protection of marine structures and alloys. These activities were expedited and in a number of cases only made possible through active participation in international co-operative research activities, particularly TTCP-TP 1, 3 and 4, and international information exchange programs ABC-8 (Materials) and ABC-36 (Naval Structures).

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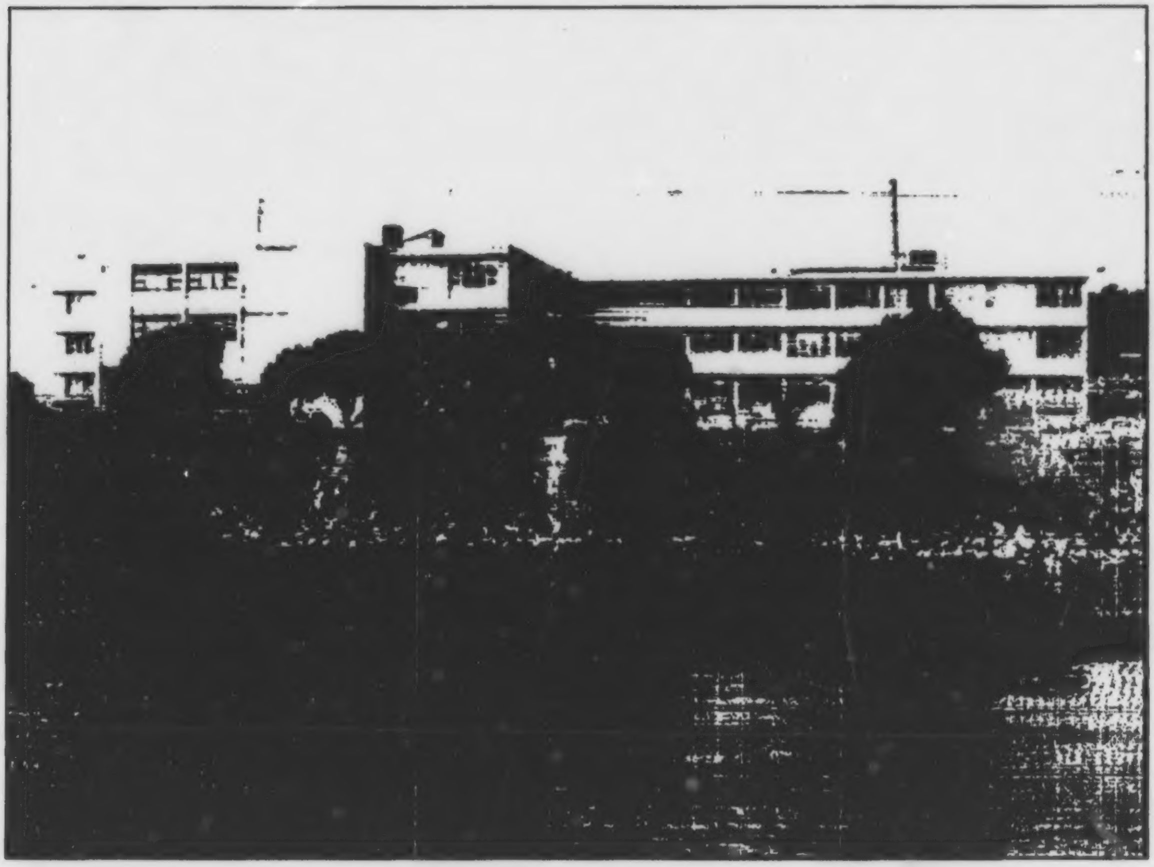
[70] In 1981, Clint Waggoner initiated a contract with AECL, Pinawa, to develop an on-line wear sensor, primarily for gas turbine engines. This collaborative project culminated in the successful development and commercial exploitation of a device, dubbed Ferroscan, which was patented in the US and Canada. A later, more advanced Total Debris Analysis System was chosen by Pratt and Whitney for incorporation in their successful bid (August 1991) on an engine for the USAF's new multi-billion dollar advanced tactical fighter. On Clint Waggoner's retirement in 1987, work on engine health monitoring became the responsibility of Greg Luoma and Harry Dominique.

Closure

Having coped for a decade with the death by a thousand cuts, DREP was about to experience the real thing. It became evident that, soon after the collapse of the Berlin Wall in 1989, the interest of the Canadian public in defence matters—never particularly high in peace-time—was about to reach a new low. Although a case can be made that this is just the time when effort should be expended on R&D and other activities with long-term payoff, we are living in the real world, where proportional sacrifice is about as good as it gets. By 1992, the Department could foresee a reduction in personnel resources by about a third. It was then decided in NDHQ that a cut of this magnitude in R&D could be accommodated more easily by closing a laboratory rather than by prorating the pain. DREP, as one of two laboratories specializing in maritime research, was particularly vulnerable. The ramifications and cost benefits of closing the laboratory and handing its responsibilities and surviving programs to another laboratory were studied in detail. Although the cost benefits seemed to be modest and the probable loss of expertise excessive, the conclusion was apparently not really in doubt. On budget day, 22 February 1994, the news of the closure was delivered to a shocked DREP staff, courtesy of a local radio station.



Building 199 in its final configuration. The extensive land-fill had been organized by Ted Fleischer, the Arbutus trees by Ralph Barer.

2. ARCTIC UNDER-ICE ACOUSTICS

A. R. Milne

Background

Arctic under-ice acoustics at the Pacific Naval Laboratory had its genesis in 1958 when imagination was stimulated by a lecture on the Arctic presented by my Section Head, Pat Nasmyth. He described his adventures on the Canadian Army's Operation Muskox—a trek through central Canada to the shores of the Arctic Ocean—and also on the Beaufort Sea in the Arctic summers of 1951 and 1952 aboard the Defence Research Board's vessel CGMV CANCOLIM II.

Before 1958, I had been engaged primarily in underwater acoustic[1] and geophysical[2] experiments in the Pacific Ocean which followed a productive ten months in 1956 as a DRB-funded visiting investigator at the Woods Hole Oceanographic Institution. There, under the direction of Dr Brackett Hersey, I had gained an extensive background in the intricacies of long-range underwater sound transmission and related ocean geophysics. (Ray-tracing in those days was done using complex analogue computers and very fussy analogue energy measuring tube-type electronics.)

Tom Hughes was my right-hand man in offshore Pacific work and continued his valued support later on in the Arctic. Another dependable hand was Richard (Dick) Herlinveaux, an oceanographer seconded from the Pacific Oceanographic Group, who took part in both Pacific Ocean and later in Arctic operations. Dick could never resist taking over as winch operator on a research ship, or diplomatically undertaking any other role when the going got tough.

For our Pacific work, we mostly used the vessels HMCS OSHAWA and CNAV WHITETHROAT, vessels operated by the Navy. For underwater sound transmission and seismic refraction studies in the Pacific Ocean, a 'shooting' vessel—usually WHITETHROAT—was needed to drop explosive charges. Later, in Arctic experiments, the shooting role was fulfilled by either a Coast Guard icebreaker in summer or a tracked vehicle or helicopter in winter or spring—but more on that later.

In 1957, I also had the opportunity to work with Dr George Shore of the Scripps Institute of Oceanography on a co-operative Scripps/PNL ocean acoustics and seismic refraction cruise in the Gulf of Alaska. I learned their latest methods for streaming hydrophones to minimize self noise, which was of great utility later on in measuring the ultra-low noise levels which occur at times in Arctic waters. I also learned a lesson on how to deal with the bureaucratic mind. Upon seeking to get into the US naval base on Kodiak Island to find a replacement electronic component, George and his technician were refused entry. I simply flashed my foreign dockyard pass, and an instant "yes sir!" got us access and the much needed spare part.

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[1] -A.R. Milne, "Sound Transmission off the Queen Charlotte Islands in November," *Pacific Naval Laboratory Report 60-5*, (April 1960).

- A.R. Milne, "North-East Pacific Long Range Sound Paths in Autumn," *Pacific Naval Laboratory Report 60-11*, (October 1960).

- A.R. Milne, "North-East Pacific Long Range Sound Paths in the Spring," *Pacific Naval Laboratory Report 61-2*, (March 1961).

- A.R. Milne, "Long Range Sound Paths off the Queen Charlotte Islands in September 1958," *Defence Research Establishment Pacific Report 63-2*, (May 1963).

[2] -A.R. Milne, "Comparison of Spectra of an Earthquake T-phase with Similar Signals from Nuclear Explosions." *Bulletin of the Seismological Society of America*, Vol. 49, 317-319, (October 1959).

-A.R. Milne, "A Reversed Seismic Refraction Profile: North Pacific Ocean Basin," *Pacific Naval Laboratory Report 60-10*, (October 1960).

Initially, the Arctic was not considered to be PNL's turf; however, despite some initial resistance, I was free to take the first halting steps toward developing an Arctic program. I cannot recall whether this freedom was by accident or design, but in life timing is crucial. When Diefenbaker became Prime Minister in 1957, one of the planks in his platform was northern development, which may have resulted in easing approval for Arctic work at PNL.

First I had to get some hands-on experience in coping with the Arctic climate. Fortunately, there was an Arctic research group in DRB/HQ in Ottawa. There, my initial contact was Trevor Harwood, a crusty bachelor and a former employee of the Hudson's Bay Company in the North. After shaking his bald head in disbelief about what I expected to do given my inexperience, he arranged for me to join a Canadian Army survival course out of Churchill, Manitoba, in March 1958. At the DRB Northern Research Laboratory (DRNL) in Churchill, I was outfitted with army-issue arctic clothing and with very thin sleeping bags, one to go inside the other. I joined a motley group of 20 soldiers, tramped for miles in minus forty degree weather, made snow caves, 'slept' in a tent (no heat), and crunched on army rations. After two days, I knew what I had let myself in for, but by then there was no turning back!

I have chosen to describe our Laboratory's under-ice acoustic research based on the order of occurrence of the field operations. This is because each field operation built upon the experiences and knowledge gained in the preceding one. Two expeditions were conducted on Arctic ocean pack ice, the remaining twenty-two were fielded in the channels, or the adjacent channels, of the Queen Elizabeth Islands. Seasonally, twelve took place in the springtime using aircraft support or tracked vehicles; nine were fielded in the summer and fall, most using an icebreaker for support. Three operations occurred in winter using tracked vehicles. All of the field operations for which I was responsible were launched in 1959 and ended before 1973 when I moved to the Institute of Ocean Sciences (IOS). During all those field operations, there was only one minor non-debilitating injury, during *Icepack 1*. There wasn't a single instance of frostbite or discomfort due to exposure to the cold. In our briefings, I stressed that we must look after each other's welfare to ensure that no one would become unduly fatigued and overexposed to the cold.

My move to IOS was fortunate for me. I was ready for a change, partly because I had reached that critical age of 53 years, and partly because of the shift in emphasis away from exploring the natural sciences to the development of underwater submarine detection systems in the Arctic. Dr W.N. English, a former associate at PNL and later at IOS, heard that I was ripe for a move. IOS needed an experienced Arctic hand to manage the Beaufort Sea Project, a project funded by both Government and the oil industry. Its purpose was to assess the environmental impacts of offshore drilling for oil in the Beaufort Sea. The scope and promise were there.

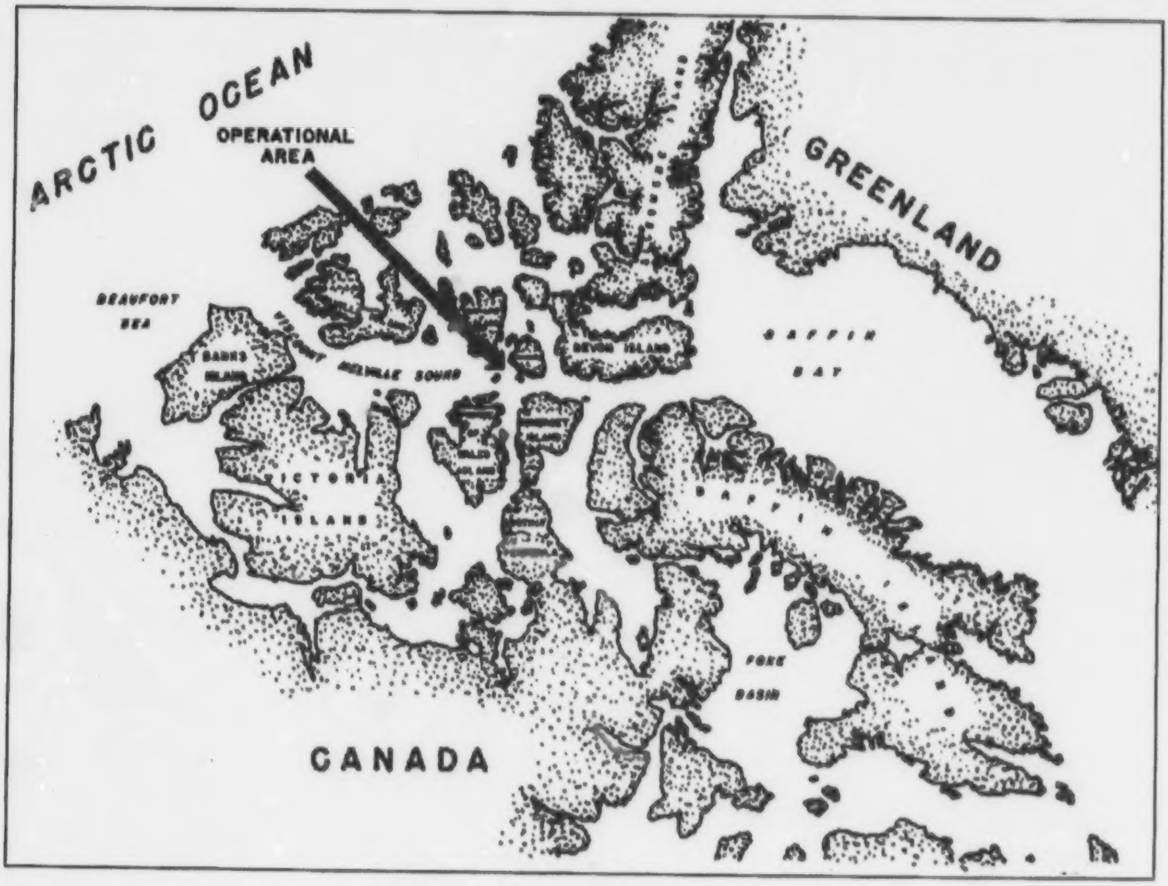
Now back to PNL's Arctic program.

Barrow Strait, April 1959, 'Paclabar'

Preparations for working on the ice of Barrow Strait

My choice of site for our first venture in the Arctic was Barrow Strait, south of Resolute on Cornwallis Island, and the time, April 1959. I had learned that first-year sea ice commonly grew a safe seven feet thick in April and in that part of the Northwest Passage would be firmly locked into the surrounding islands. Also, the Canadian Air Force would be involved in their springtime re-supply operations, so that I was confident that not only could our equipment be flown to Resolute but we could temporarily be housed either at the RCAF base or at the Ministry of Transport weather station in Resolute. Trevor Harwood and Cdr Jim Croal, from DRB Ottawa, offered to act as shepherds, made local and logistical arrangements, and eventually assisted with the field work. Incidentally, Barrow Strait was of interest to National Defence, being part of a channel navigable by submerged submarines.

Our crew numbered eight. In addition to Jim Croal and Trevor Harwood, John O'Malia and Carl Kelly were seconded from PNL's Engineering Section. Tom Hughes was senior technician and I was crew leader. It was fortunate that Professor Elton Pounder and Paddy Stalinski from McGill University's Physics Department had agreed to join us to analyse the physical



Location of *Paclabar* experiment

properties of the ice. Trevor Harwood hired an Inuit guide, Jackoosie, complete with dog team, to guide us on the sea ice (and later to transport the McGill contingent to our base camp from Resolute).

During the summer and fall of 1958, our small group at PNL became heavily involved in the design, construction, testing, cataloguing, and packing of field equipment. We also completed an explosives handling course given by the Navy Demolition Group in Esquimalt. I assume we all passed since all four of us survived detonating everything from plastic explosives to shaped charges, in addition to the type of explosives and detonators we would be handling in the North.

All field equipment and southern personnel were initially flown by RCAF C119 'Box Car,' directly from Victoria or Ottawa to Churchill, where assembling and testing took place. The air cargo included: two Bombardier J5 tractors (the kind used in Montreal to clear sidewalks of snow), two wooden cargo sleds from Norway, two steel log-carrying sleds, explosives from CIL James Island, hydrophones, recording electronics, ice-core analysis gear, chainsaw engine-powered ice augers, winches, battery chargers, and numerous boxes of equipment and spares. Army-style arctic clothing and caribou skins were drawn from the stores of DRNL while the Army had provided us with field rations, two arctic tents, sleeping bags, and cooking gear. Carpenters in Churchill had constructed two 'wannigans'—insulated huts—designed to perch

***Paclabar* field party: Paddy Stalinski, John O'Malia, Elton Pounder, Trevor Harwood, Al Milne, Carl Kelly and Tom Hughes**

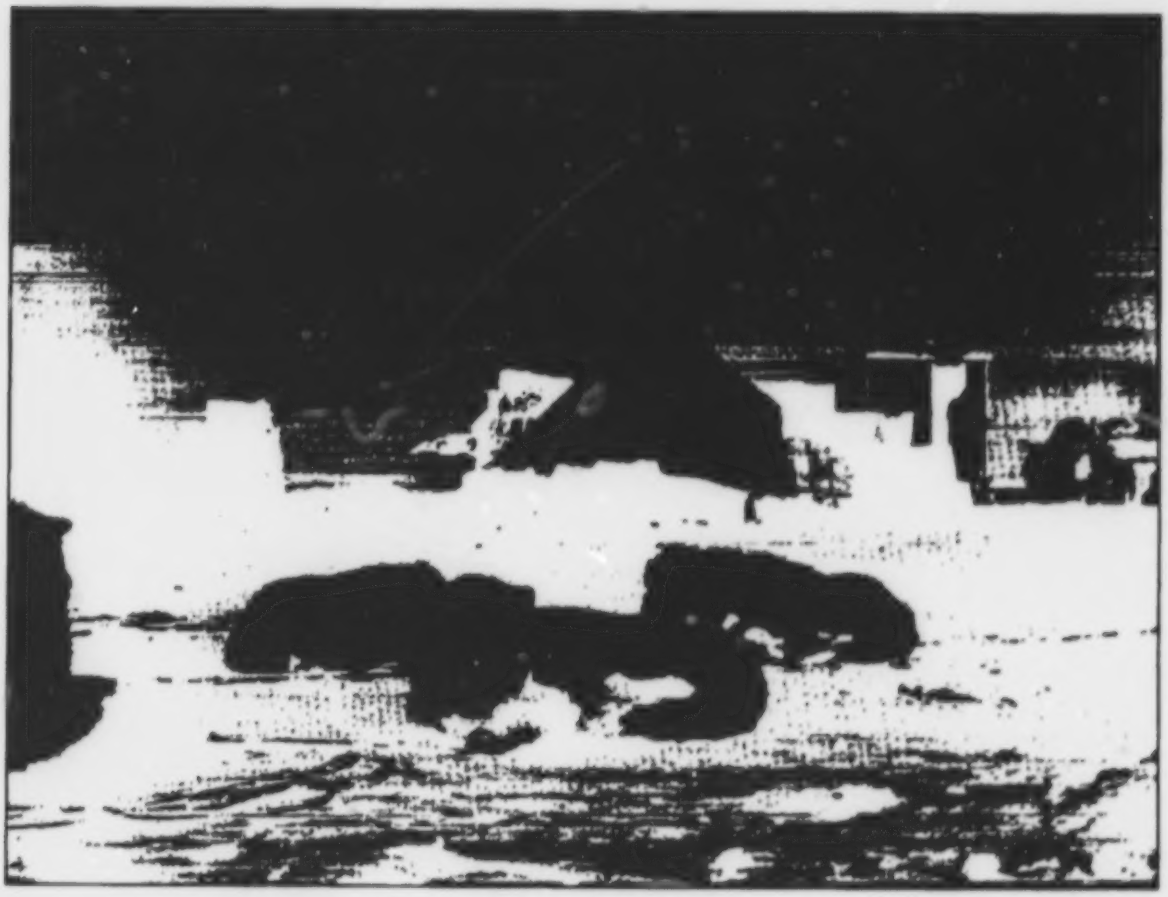
on the steel logging sleds to be towed by the tractors. These heated huts were used to cook in, house ice physics equipment and electronics, and each could sleep up to four bodies; depending on room available, any overflow crew, including myself, would sleep in the frigid tents. By prior arrangement, vehicle and stove fuel in ten gallon drums and temporary accommodation were waiting for us at Resolute courtesy of Bill Fedorak, manager of the MOT weather station.

Finally, we were flown from Churchill to Resolute by RCAF C119 and by mid-April we were ready to move out onto the sea ice of Barrow Strait.

By now, you the reader, may be wondering how all this was going to work. The answer is that it did, but with many difficulties as you will see. Despite our problems and inexperience, the planned work was done, and we learned how to improve our comfort and efficiency for the future.

Paclabar field work

Jackoosie and Trevor Harwood did a reconnaissance of ice conditions and recommended a route along a wide ice-foot around the southwest of Cornwallis Island to an area of ice more free of pressure ridges. There we might be able to set up a base camp and be able to run



Camp in Barrow Strait

Al Milne

a tractor line southwest into Barrow Strait[3] along which underwater explosives could be set off, their sounds to be recorded at the base camp. We set off the next day in the glaring brightness, avoiding patches of impassable rough ice, to a location for the base camp, 12 miles offshore over water 380 feet deep. Near the camp, a large hole was blasted through the seven foot thick ice. This hole was made by immersing a string of three one-lb charges set in a flooded drilled hole at the centre of a ring of dry holes (ones not drilled completely through the ice). After much shovelling, a depth sounding was made followed by a hydrographic station, the latter to be used for calculating the speed of sound in water as it varied with depth. I found that the drain cock on the metal hydrographic bottles promptly froze when brought to the surface. Samples of sea water could only be obtained for future analysis by quickly taking each hydrographic bottle, as it was brought to the surface, into the heated hut for draining into glass sample bottles. (In the future, to avoid this problem, we would always have a heated shelter over the hydrographic hole.)

Tents were erected and Jackoosie showed us how to make snow walls as windbreaks. An outhouse from snow blocks was built, in a classical Greek design, around a dry hole drilled in the ice over which John O'Malia mounted his prized plywood toilet seat brought all the way from Victoria. This facility was most important since not only did Jackoosie's dogs enjoy a bit of human excrement but the constant wind could drift any contaminated snow to where snow blocks might be cut for melting on the stove.

The army field rations were not gourmet fare. After six weeks in the field, we all began to suffer from cracked skin on our hands, which we attributed to lack of adequate nutrition. None of our future expeditions, where we provided our own rations, was likewise afflicted. Gasoline cook stoves leaked and were frequently thrown outdoors into 'the biggest refrigerator in the world' before the flames burnt down our kitchen wannigan. The Army-supplied parkas were not very windproof, although the mukluks and mittens were excellent. In the tents, untanned caribou skins were used for insulation under our sleeping bags. These shed hair, which found its way into our mouths by morning—no pillows of course, except for Jackoosie, who produced his own down pillow from a storage box on his komatik.

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[3] A.R. Milne, "Shallow Water Under-Ice Acoustics in Barrow Strait," *Journal of the Acoustical Society of America,* Vol. 32, 1007-1016, (August 1960).

Once the base camp was set up, the hydrophone used for listening to explosive sounds was deployed. Its mounting was in the same configuration used previously for ship-supported listening in the Pacific Ocean. It consisted of a neutrally-buoyed hydrophone, connected by a 30 foot long neutrally-buoyed cable to a preamplifier in a pressure case. The preamplifier case, acting as a weight, was attached to an electrical cable wound on a winch. This cable was labelled with depth markers and connected to sound recorders in the wannigan. The neutrally-buoyed hydrophone and cable were completely flaccid in sea water and prone to tangling unless there was some water motion to stream them away from the winch cable and preamplifier case. Stuffing the hydrophone down the hole, through ice seven feet thick, was like pushing on the end of seaweed! Tom, always creative, solved the problem by attaching a lead weight to the hydrophone using a candy lifesaver which dissolved and dropped the weight by the time the hydrophone was at its deployment depth of 300 feet.

John O'Malia and Carl Kelly became the shooting party driving our two tractors, one towing a wannigan. Accompanying them were Elton Pounder and Paddy Stalinski who analysed ice cores at the eleven locations where underwater explosives were detonated along a ten-mile long track to the southwest of the base camp. Locations were marked by small towers of snow blocks topped with black cloth. These became targets for curious polar bears who knocked most of them over. (We learned that bamboo poles worked better and these became

John O'Malia and Carl Kelly with J5 tractor and wannigan

standard markers in future field trips.) At each location, John and Carl would alert Tom and me by radio that they were preparing to fire a shot. They would fire up the drill motor, drill through seven feet of ice, wire up the detonator, insert it in the one-lb Nitrone explosive, lower it on the end of depth-marked wire from a winch, and connect it to a battery-powered 'firing box,' which was connected in turn to the radio transmitter. After being alerted at the base camp that they were ready, we would cease all moving around to ensure quiet reception at our hydrophone, start running the battery-powered amplifiers and tape recorder, and make our announcements on tape (heard by John by radio). When John pushed the firing button, its signal sent by radio was also recorded on tape, allowing a precise distance from shot to hydrophone to be determined.

John and Carl would then pack up and move an estimated one mile further away. It sounds easy, but that one mile often took many hours, requiring routing around ice ridges, one tractor sometimes having to tow a bogged-down tractor and wannigan, and then having to contend with refuelling, ice-fog, and -20° C air temperatures. (We learned that the steel sled and wannigan combination was far heavier than necessary and was often beyond the towing capability of our small, narrow-tracked J5 tractors.)

To make ambient noise recordings, we lowered a tripod-mounted hydrophone to the bottom. Ambient under-ice noise levels were seldom above instrument self-noise except for frequencies below about 40 Hz. We had never experienced these extraordinary low-noise levels anywhere else. We could hear the croaking sounds of two seals but could not find them nearby; we could hear the squeals of Jackoosie's komatik runners when he was miles away; we could hear the footsteps of his dogs as they became restless when tied up; there were none of the ice-cracking noises and wind speed-related noises experienced in later expeditions. The low-frequency noises we did record were apparently due to 'organ pipe' pressure waves induced by slight vertical motions of the ice sheet, perhaps induced by wind turbulence.

We took the opportunity, when a hydrophone was on the bottom, to measure the speed of sound as it varied within the sea bottom by using the seismic refraction method. For this purpose we recorded the sounds from one-lb charges detonated on the sea bottom at various distances out to 6,000 feet from the hydrophone. Also we recorded flexural waves in the ice sheet when induced by one-lb charges fired four feet above the ice and also within the ice as detected with a surface mounted geophone (borrowed from Energy, Mines and Resources in Victoria). The resulting 17.5 Hz waves gave a computed ice thickness of 5.75 ft, short of the actual 7.0 ft. The conclusion was that the bottom 1.25 ft of the ice did not contribute to its rigidity, this being verified by mushiness at the bottom of the ice experienced when drilling holes.

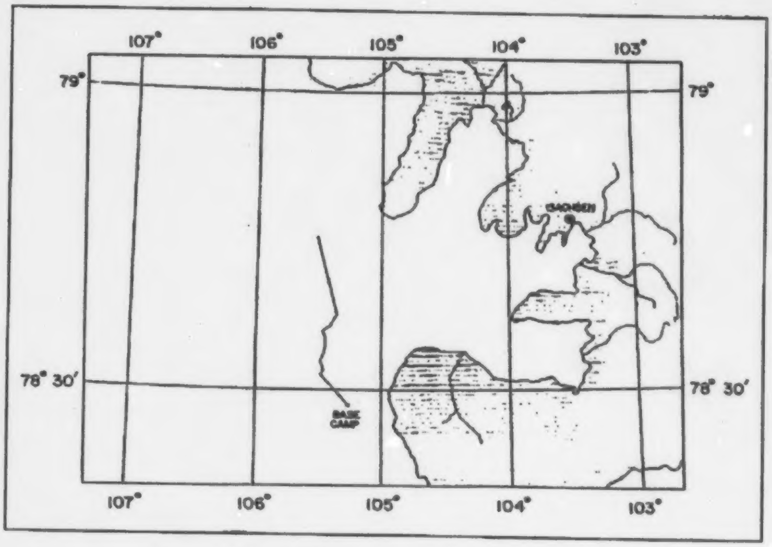
All this serious stuff was rudely interrupted by a hungry, curious and aggressive young polar bear, which was eventually shot by Jackoosie once he got his hands warm enough to fire his rifle. I have the rug, which is several sizes smaller than the fur coat on the bear depicted in an article written by Cdr Croal for the 5 September 1959 Toronto Star Weekly News Magazine. You can never entirely believe a fisherman or a budding Arctic explorer!

As a direct result of the success of *Paclabar*, DRB/HQ now had token West Coast Arctic scientists to display, because in May 1960, Tom Hughes and I were invited on an Arctic tour hosted by the RCAF with the Chairman of DRB, Dr Zimmerman, as the main guest. In an RCAF Viscount, we visited all the Eastern weather stations and flew around Ellesmere and Axel Heiberg Islands, ending up at Resolute. At Resolute, we fished for Arctic char, after drilling through the ice with PNL's drill and warming up in our old abandoned wannigan. Of course, Trevor Harwood's hand was deeply implicated!

Prince Gustaf Adolph Sea, April/May 1961, 'Icepack 1'

Planning for working on the ice west of Ellef Ringnes Island

The landfast ice of Barrow Strait in the springtime, on which *Paclabar's* work took place, is not typical of the year-round ice cover over the seas around most of the Queen Elizabeth Islands. West and north of Barrow Strait there is mostly multi-year ice which partially survives the summer's melting and is refrozen in winter as a matrix of new ice and ice of various ages. The oldest ice, called polar ice, develops humps on top, and becomes harder as brine is leached into the sea below. In the fall, pressure ridges rim wind-driven ice floes and islands as the ice becomes landfast. These physical features of multi-year ice made clear the need to categorize their under-ice acoustical properties.



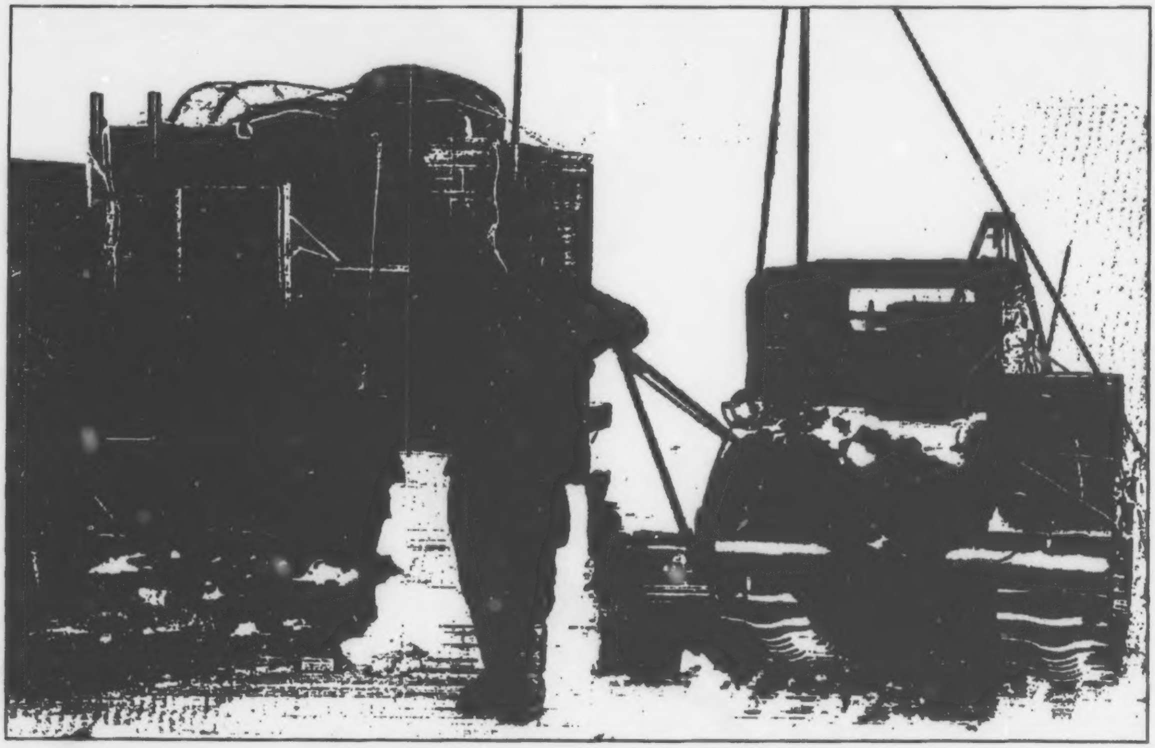
Location of *Icepack 1*

Fortunately, in April 1958, the *Polar Continental Shelf Project* (PCSP) was established by a Cabinet directive, and by the spring of 1961, their first base was to be in operation at the location of the Joint Arctic Weather Station at Isachsen, Ellef Ringnes Island. The Project's mandate not only included support for geological, geographic and hydrographic surveying by the then Department of Mines and Technical Surveys, but also support for field work initiated by universities, museums, and other government departments. Since Isachsen was an ideal jumping off place for an under-ice acoustic assault on Prince Gustaf Adolph Sea to the west, I proposed to do springtime field work in that sea similar to *Paclabar's* program in 1959. After program and budget approval by PNL, Fred Roots, PCSP's director and field manager, kindly agreed to provide us with base accommodation, radio monitoring, tractor fuel, stove fuel, and aircraft re-supply sorties. The RCAF agreed to airlift our tractors, sleds, wannigans, all our supplies, and our crew with a special C130 Hercules flight from Victoria directly to Isachsen.

Back at PNL, detailed plans were brought to fruition during the summer of 1960 and the following winter. Our mobile equipment was to consist of three tractors each towing a sled-mounted lightweight wannigan. Our original two Bombardier J5 tractors were shipped back from Resolute for refitting in PNL's shops, where cabs were modified to have sloping-forward windscreens (much better to deflect snow and low sunlight), and escape roofs. The third J5 tractor was airlifted from Ottawa. One tractor was equipped with an engine-powered, fold-down drill-rig designed by Graeme Dennison to drill through twelve feet of sea ice. In January 1961, Tom Hughes, Graeme and I loaded the tractor onto PNL's truck, drove it north to the Cariboo and tested the rig on lake ice.

Our field crew consisted of dour, meticulous Tom Hughes, the oldest; light-hearted Carl Kelly; John O'Malia with his barbed wit; multipurpose Dick Herlinveaux (seconded again from the Pacific Oceanographic Group in Nanaimo); and myself. Phil Langleben from the McGill Ice Research Group joined us later at Isachsen, arriving on a PCSP charter flight. (Bill English, at that time deputy superintendent of PNL, accompanied us to Isachsen to record low-frequency magnetic observations and later spent some time on the ice with us.) Those at PNL brushed up on astro-navigation using a bubble sextant borrowed from the RCAF. We planned to use it to obtain sun angles and calculate position lines. These with radio bearings—a magnetic compass being useless that close to the magnetic pole—were used later on Prince Gustaf Adolph Sea to fix our locations.

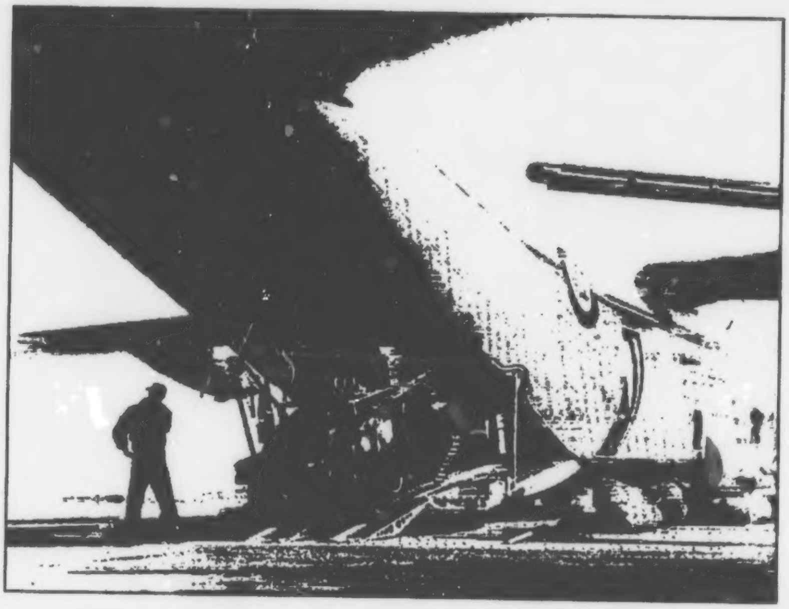
Abandoned at Resolute were our heavy steel sleds and wannigans. (These ended up as fishing shacks on a nearby lake.) Three new light-weight wannigans, made in Sidney by Fairy Aviation, were designed to be disassembled for airlifting. They were named 'Empress,' 'Frontenac,' and 'Royal York.' Cozy inner liners for our army-type clothing were made for us by Jones Tent and Awning and we purchased Woods Four Star Arctic sleeping bags and foam pads to use under them. Twenty Fiberglas cargo boxes were made in the Dockyard—some being designated as food boxes. A month's rations were carefully selected for ease of cooking, palatability, and ability to stand up to being frozen in 'dry ice.' We spent a few hilarious hours prescrambling eggs and sealing them in meal packets. Two tents with pneumatic 'poles' were modified by adding insulated pads to the interior and joining them with an insulated tunnel. These were to be used at our base camp on the ice for supplementary accommodation. We made many changes in our field equipment and ways of doing tasks in the field, each one of us con-



John O'Malia relaxing outside the Empress tributing ideas based on experiences on *Paclabar* in 1959. Explosives and detonators were shipped to Isachsen in advance of our departure. New electronic and underwater components were tested in a walk-in food freezer for low temperature survivability. A critical item was our new ultra-sensitive hydrophone, a replacement for the relatively insensitive one used on *Paclabar*.

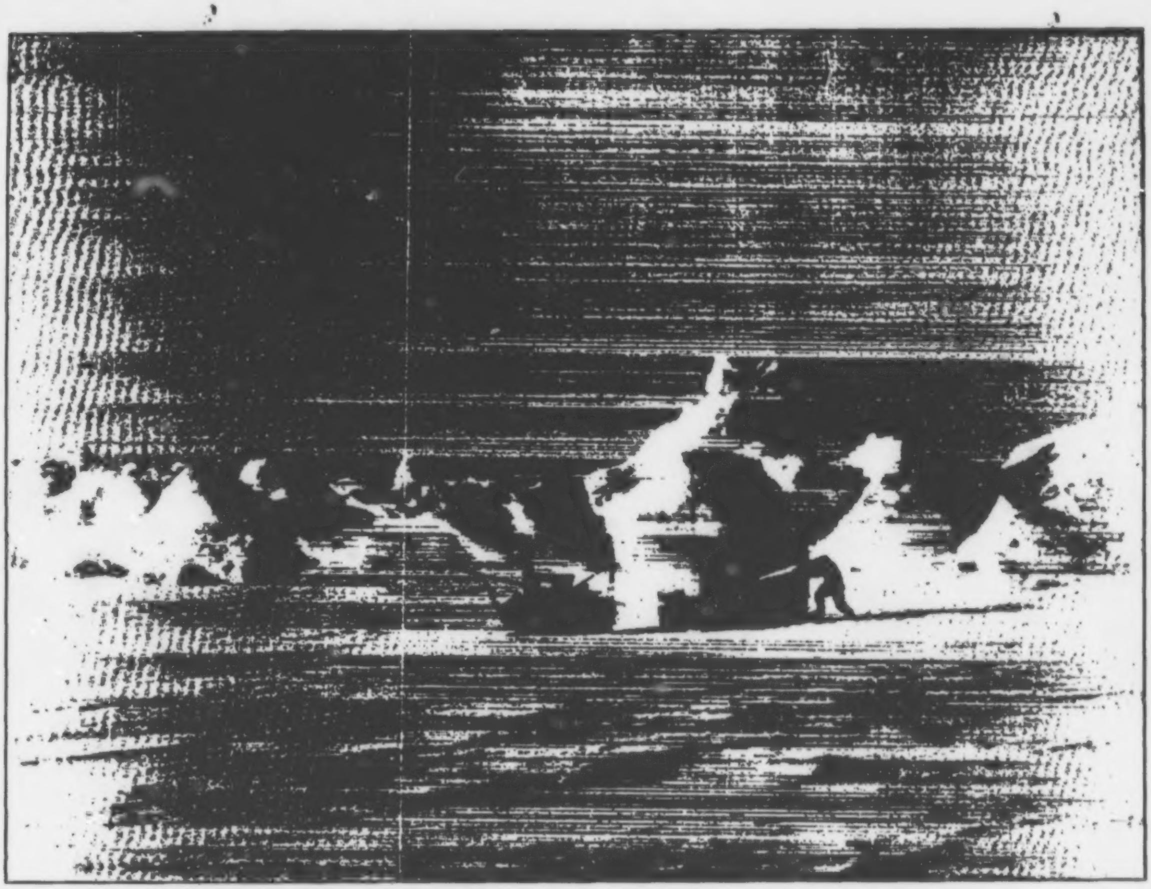
Icepack 1 field work

It was a warm 14°C in Victoria on March 27 when we drove our snorting tractors into the rear ramp of the huge C130 Hercules aircraft and anxiously loaded and tallied our remaining equipment—all 18,000 lb of it. Saying good-bye to our families, we took off with a horrendous roar, trailing a plume of black exhaust to fly for six hours northward. During this time, each of us found a resting place on top of our cargo and stuffed our ears to squelch the incredible noise. Landing at Isachsen, 800 miles south of the North Pole, we were hit with a taste of the future with the air temperature at a chilly -45°C. Even though we had changed into our arctic clothing before landing, there was a distinctly unwelcome feel in the air. We adapted fairly fast to the cold but the tractors quickly died as their carburettors tried to ingest the ice crystals in their fuel. The next problem was our viscous, 10W30 crankcase oil—how embarrassing to avowed arctic experts! We spent almost a week, partly getting our tractors acclimatized using frost-bitten fingers to work in frigid, almost inaccessible engine orifices, partly working on ice-drills and communication facilities, sorting cargo, reassembling wannigans and mounting them on sleds. By April 4, we were ready to venture out over the land and onto the ice, indeed eager! The Polar Shelf facilities were exceedingly primitive. Each morning, breakfast consisted of two cold hard-boiled eggs, a slice of Spam, and ersatz orange juice. Sanitary facilities rated a D-minus. Rumours circulated that the poor conditions were by design and were Fred Roots' method of encouraging investigators to get out into the field fast!



J5 tractor being loaded on Hercules at Victoria Airport

Getting onto the ice of Prince Gustaf Adolph Sea took us three days. In early April, it was still dark enough at night to prohibit travelling. We had to poke along the hilly, gully-cut shore looking for a gap in the 50 ft high piles of rafted and uplifted ice extending miles along the shoreline. We had recurring delays with one tractor and it was necessary to clean out its fuel tank, which contained twigs and earth presumed to have been put into the tank on its trip by rail to Esquimalt. We took turns jogging and walking ahead of the slow-moving tractors, scouting for safe routes over steep, snow-covered hills and around precipitous gully walls. At one point I became thirsty and without thinking grabbed a piece of ice. As I was putting it in my mouth, it froze onto the end of my tongue with a sickening sizzling noise. I had no choice but to pull it off along with a patch of taste buds. Ouch!



Scouting the ice ridges

A potential gap was eventually found and after it was attacked with axes and chisels the barrier was broached. From there, the route to our base camp was through fields of very rough ice requiring scouting forays on foot and axe work. Carl nicked his foot with his axe, unknown to him until his blood oozed through his mukluk. We had no sutures or anaesthetic but Dick, always resourceful, had some nylon fishing line. I had a sewing kit. Also, Dick Sewell had supplied us with ethyl alcohol from PNL's chemistry laboratory. Carl's foot was bathed in alcohol while a generous dollop of alcohol, mixed with orange juice crystals and water, provided him with an internal anaesthetic. The three centimetre long cut, although deep, was not potentially disabling but I was amazed how tough skin is and how much force was required to sew the wound closed! Fortunately, there were no complications and Carl seemed as good as new and had his stitches removed when we got back to Victoria.

By April 8, about five miles offshore over water 457 m deep, we found a suitable site for a base camp at the end of a field of smooth ice where we could be supplied by a fixed-wing aircraft. Bill English flew in to join our crew at the base camp and thereafter waxed poetic about the virtue of the pilot biscuits he had insisted we include in our rations. Of course most of us would not ingest these disks and various rude suggestions were made for their use and disposal.

The following ditty, Bill being the acclaimed author of the lyrics, was sung at PNL's 1961 Christmas party and hints at the camaraderie that developed during some very tough going in April 1961 (and the virtue of pilot biscuits![4]).

Ode to Al 'Fearless Leader' Milne

(Tune: When the Ice Worms Nest Again)

There's a frozen ocean waiting in the Arctic,
It waits for me but does not wait in vain,
For some day I'll grab my mukluks and my parka,
And go north when Fearless Leader calls again.

In the land of the pale blue snow,
Where it's 99 below,
And the Bombardiers go roaming o'er the plain,
In the shadow of the Pole,
We will drill another hole,
We'll go North when Fearless Leader calls again.

For our rations we will dine on pilot biscuits,
In our wannigans we'll roam the frozen main,
Helicopters will look down on us and wonder,
Why we come when Fearless Leader calls again.

When some night at halfpast two,
We are gulping down our stew,
After toiling all day with hands and brain,
We'll complain about our ration,
As we take another station,
Then turn in till Fearless Leader calls again.

One main task of the expedition was to record underwater ambient noise at the base camp. Another main task was to record the sounds of underwater explosions set off at increasing distances from the base camp. The latter task entailed navigating over and between hummocky polar floes with two tractors, one dragging a sled loaded with a wannigan, fuel, explosives, food, and other essentials, and the other equipped with the drillrig.

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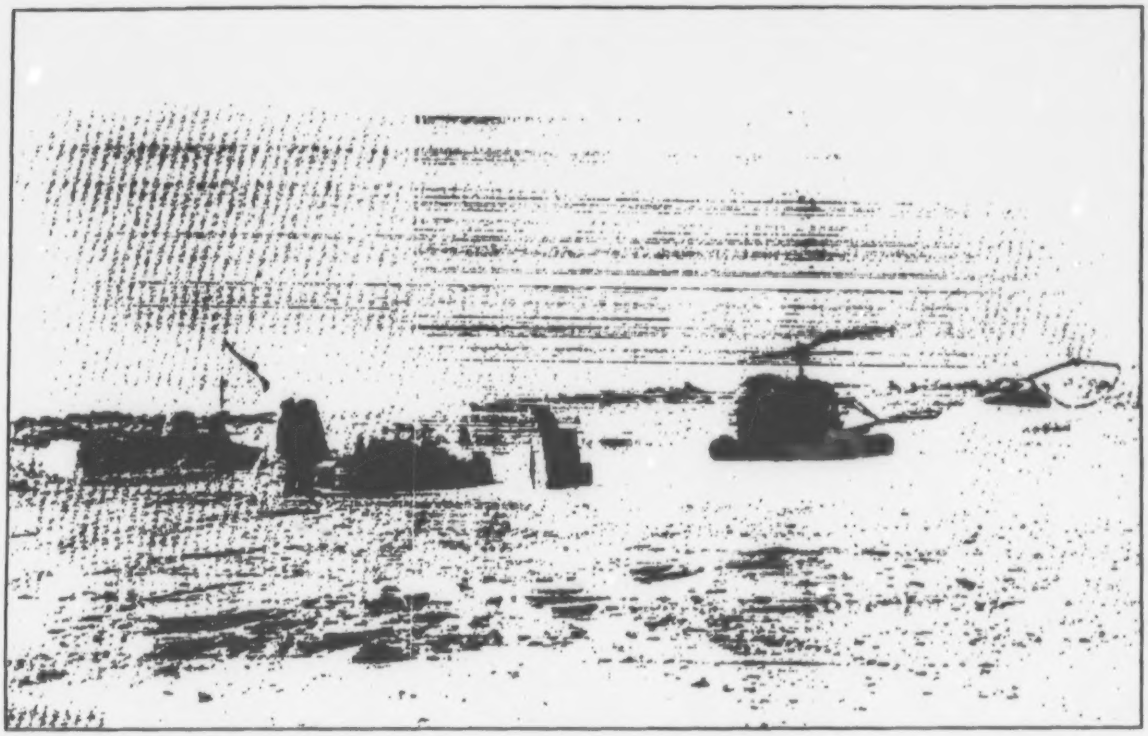
[4] Shortly after our return from *Icepack 1*, Dr English was appointed Director General of the Bedford Institute of Oceanography. As a going-away award he was presented with a pendant commemorating his Arctic contributions. This consisted of a pilot biscuit—preserved in epoxy resin—and bars recounting his other exploits on *Icepack 1*.



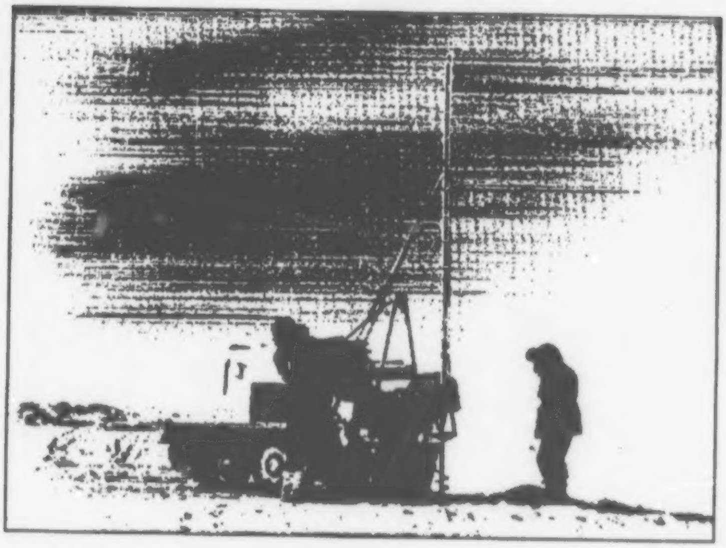
Helicopter about to take off for aerial reconnaissance

Before setting out on the 'shooting run,' we requested a supply flight from Polar Shelf's base to deliver Phil Langleben to our camp to commence his work on the physical properties of the ice. As the ungainly Sikorsky 'horse' helicopter landed, a tractor was inadvertently driven under the slowly turning main rotor blades in order to unload our fuel. The whip antenna on the tractor was clipped off by the rotor blades, at the same time scouring their underside. This incident went unnoticed at the time and the helicopter took off on an uneventful trip back to Isachsen. The next day, we heard from Fred Roots that the helicopter blades were deemed unsafe and had to be replaced at a cost to Polar Shelf of $30,000 and a week's down time. Our popularity rating took a beating, but Fred took it all in his stride and put it down as a cost of working in the Arctic.

The shooting party, initially Carl, Dick, Phil, and I, set off in a northwest direction where an aerial reconnaissance had revealed a series of frozen leads linked by polar floes, hopefully somewhat more navigable than the jumble of ice to the west. A whiteout, clear weather, then a blizzard was the usual pattern. To keep in a constant direction, a line of black flags on tall bamboo poles was set out by forward scouts on foot while the tractors weaved around obstacles. This was a slow process during whiteouts. Frequently the tractor towing the wannigan became bogged down and two tractors had to be linked to extract the wannigan. One-lb explosives were detonated at depths of 91 m and 244 m at sites located at intervals of roughly 800 m on a track 33 km long. At each site, Dick used the drilled hole to collect water samples and record the water depth while Phil took ice cores for analysis. It was a tough, chilly routine. Dick's log notes that Carl's birthday was on April 12. 'For his party we had a cake and a bottle of trouble eraser.' Apparently ice crystals in the liquid were not a problem.

Meanwhile, back at the base camp, Tom and John, in radio contact, faithfully recorded the explosive sounds. Later, I switched places with John, using an Otter re-supply flight, and got going on ambient noise recordings sensed by our sensitive bottom-mounted hydrophone. For the first time we noticed major differences in the underwater noise as the air temperature changed—ice cracking noise becoming stronger as the air chilled.[5] It was also evident that the wind speed (indicated by our anemometer) was directly related to a rise in 'hissing' noise which was not detected by our insensitive hydrophone used on *Paclabar* in Barrow Strait.

Al Milne placing navigation flags



Carl Kelly drilling a hole through the ice

Then it was mid-May; our work was complete and we headed back to Isachsen, now over a proven trail. I requested a C130 flight back to Victoria via Resolute; this was confirmed for a date allowing us time to pack up and disassemble our wannigans. The weather then closed in with blowing snow and we had nothing to do but hole up in our sleeping bags for ten boring days! Finally, the C130 sneaked in under the overcast and we loaded our gear—some being airlifted to Resolute, where a J5 tractor and a wannigan on a sled was to be used in the following summer. Left behind was our remaining heavy equipment, some of which I anticipated using on Prince Gustaf Adoph Sea in 1963.

By late May we were home, glad to be with our families, enjoying the warm weather and feeling satisfied that our plans had worked well, but my little Robbie would not look at me until I shaved off my beard!

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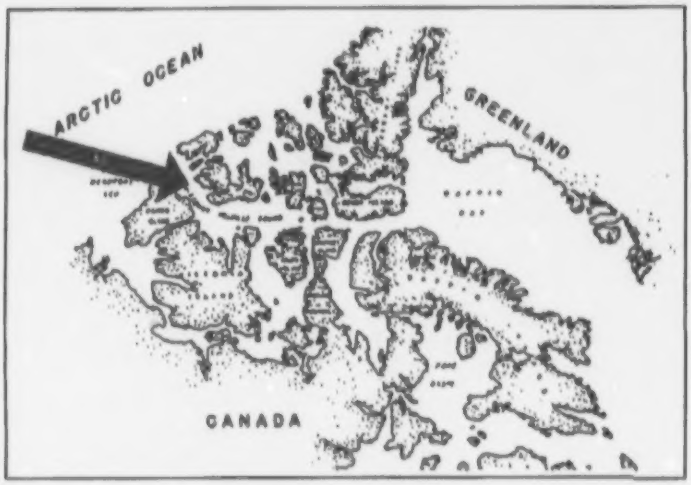
[5] A.R. Milne, R.H. Herlinveaux, and M.P. Langleben, "Acoustics Under Arctic Sea Ice: Prince Gustaf Adolph Sea in April and May, 1961." *Pacific Naval Laboratory Report 63-1*, (January 1963).

M'Clure Strait, August/September 1961, 'Icepack 2'

Planning to work from an icebreaker

We didn't have much time to get ready for a summer program. As soon as I returned to PNL, I made a request through DRB/HQ for icebreaker time in the general region of the Northwest Passage to the west of Resolute. I knew that by mid-August, there would be at least one ice-breaker in the area which would have finished shepherding cargo ships on the sea-lift to Resolute. By then, Lancaster Sound to the east is usually ice-free and an icebreaker would usually deadhead back to its Eastern port. The hoped-for time to the end of September was expeditiously granted. It was to be the 'Wind' class icebreaker, CCGS LABRADOR, skippered by Captain P.W. Tooke. In the meantime, Bill Burroughs and Robbie Robson, both in Harry Davidson's section at PNL, were hinting that the Arctic had a 'certain appeal.' Both of these adventurers, with Tom Hughes and me, eventually comprised the PNL crew for *Icepack 2*. Professor Elton Pounder, head of McGill's Ice Research Group, would join us at Resolute. Most of our field equipment was already stored, courtesy of MOT, in Resolute. All that was required was to take north additional spares and sort out our equipment for lightering to LABRADOR, and also make arrangements there for transportation, a crane, stevedores, and temporary accommodations. Finally, the RCAF would provide us with C130 Hercules flights to and from their base at Namao, Alberta, in conjunction with their regular Northern re-supply flights.

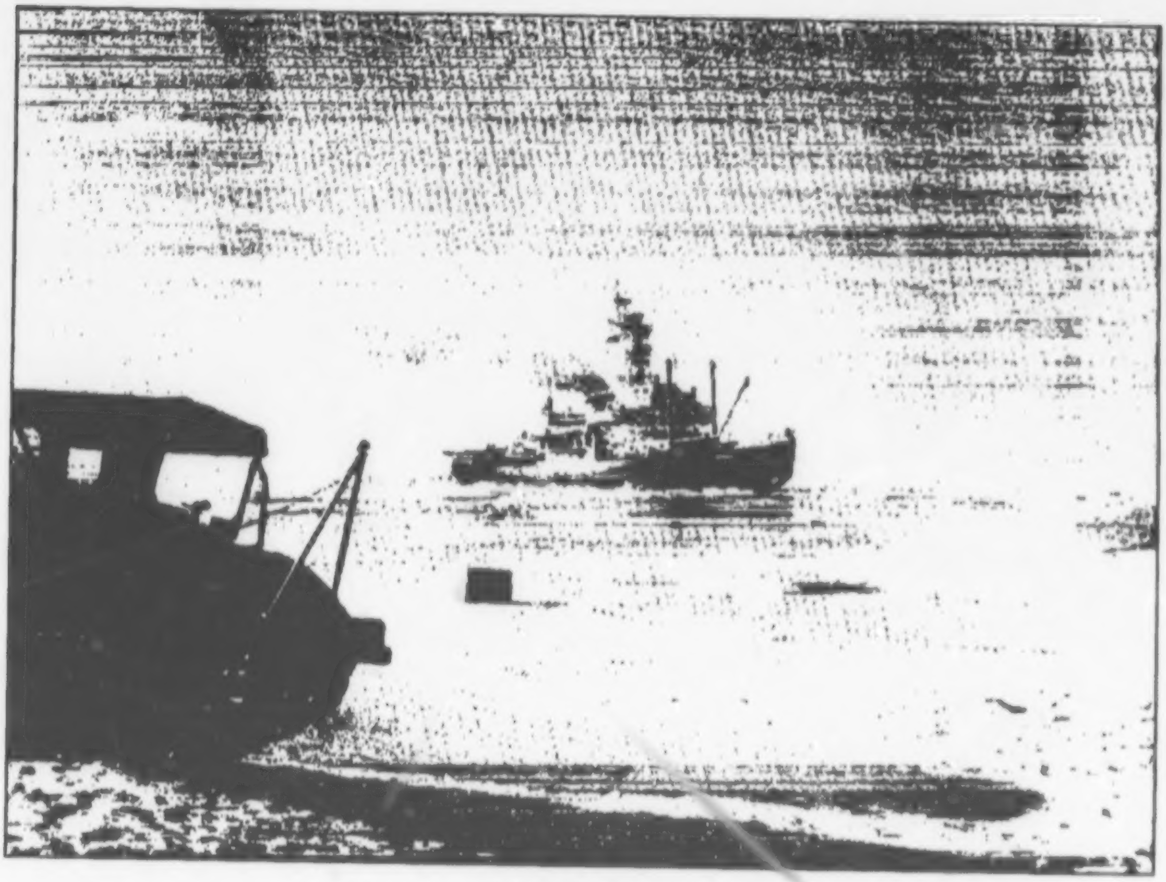


Location of *Icepack 2*

Our plan was to conduct under-ice acoustic measurements and ice core analysis from a camp on an icefloe in a region of complete ice cover. Ambient noise and reverberations from local explosions would be recorded at the icecamp. The icebreaker's helicopter would be used for transporting the shooting party over the ice for making underwater sound transmission measurements.

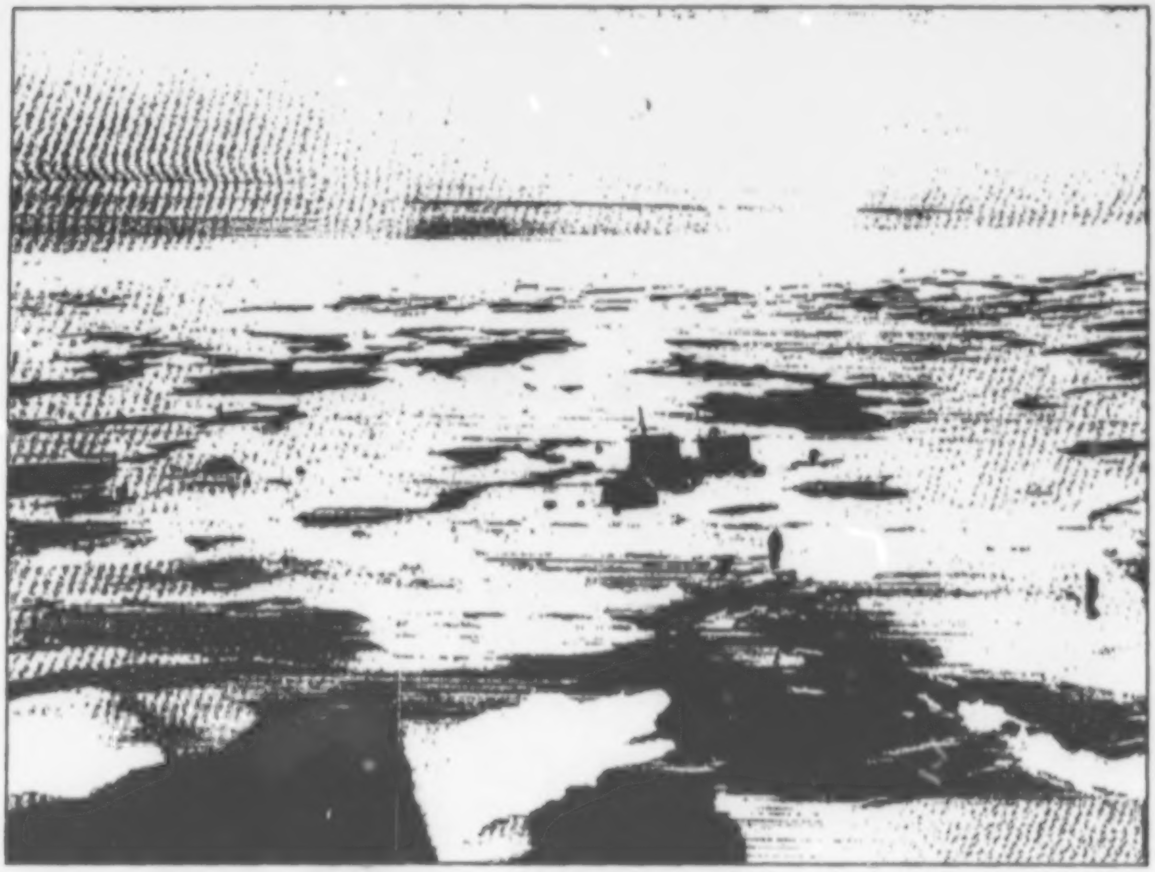
Icepack 2 field work

When the white superstructure and black hull of LABRADOR emerged above the horizon of loose ice off Resolute, I radioed that we and our cargo were ready to go. The ship's Bell 206 flew us out to the ship where I conferred with gruff, rotund Captain Tooke, who had no prior information about our plans. In our brief conversation I knew all would go well, and in a few hours our two wannigans-on-sleds, our J5 tractor, and the rest of our cargo were lifted off the lighter by the ship's crane and stored on LABRADOR's foredeck. I then met with the Captain and his First Officer and reviewed our plans. Captain Tooke recommended that we would likely get our desired ice conditions in M'Clure Strait, toward the western end of the Northwest Passage. The ship would provide us with the food, water and helicopter support, and would search for a safe ice floe on which we would establish our camp, expecting to stay on the ice for two weeks.



LABRADOR

For the next three days, LABRADOR headed west, travelling in leads and polynas, crunching through rotten first-year ice, and skirting increasingly more numerous old polar floes. It had no need to use all six of its 5,000 hp diesel engines, four having sufficient power to break the ice we encountered. We had a taste of East Coast fare with cod tongues on the dinner menu at least three times. Meanwhile, on the foredeck, we tested our electronics in the 'acoustic' wannigan while Elton set up his ice physics apparatus in the other wannigan. When a suitable polar floe was eventually identified, I checked it out from the air using the helicopter and then landed and walked around its blue-hued pools and hummocks. LABRADOR was then eased against the floe and the ship's crane used to unload our camp, the tractor first, which then towed the wannigans out onto the floe. Captain Tooke left a skiff with us in case the floe broke up. Later, Robbie used it as a comfortable place to sit while arming explosive charges. An important piece of equipment was our low-frequency homing beacon. Icebreakers are noisy ships at the best of times so it was necessary for LABRADOR to stand-to about ten miles away to prevent acoustic interference with our measurements. We were easily found by the helicopter, which could home in on the beacon.



Icepack 2 camp on polar floe

The ice floe consisted of hard blue ice, a substantial 4.5 m thick—about the design limit for drilling holes with our tractor-mounted drill rig. After drilling, blasting and cleaning out ice chunks, the hydrophone winch was set up on planks over the hole. After LABRADOR had vanished acoustically, we began our series of ambient noise recordings using our sensitive tripod-mounted hydrophone set onto the sea bottom 485 m below. On completing a recording, our portable drill motor, adapted to power the winch, was then used to lift the hydrophone off the sea bottom to avoid dragging it as the ice slowly drifted. Reverberations generated by local underwater explosions were also recorded, from which backscattering strengths related to under-ice roughness were deduced.

Arctic foxes in their summer coats paid us a few furtive visits; a polar bear passed through our camp unknown to us except for its barely discernible pie-plate sized tracks .

For the first time in our Arctic work, a helicopter was used as a 'shooting' vehicle. Robbie Robson and I were the shooting party, while Bill Burroughs and Tom Hughes manned the recording system. In the small Bell 206, we carried a box of one-lb charges, detonators, a 'blasting' box, a radio, an ice-drill and motor, motor fuel, a winch holding 100 m of blasting wire, and survival gear. The procedure was to establish an approximate track aided by a sun compass if possible, estimate distances by flying time, land on thin young ice or at the edge of a floe, and then unload. The helicopter would then fly off to land and idle while Robbie and I contacted Tom by radio after a charge had been armed and immersed to depth. The blasting box was then connected to the radio and the firing button pressed. After Tom was happy with his recording, we called back the helicopter by radio, loaded our gear and headed off to the next shot site.

Robbie Robson and Al Milne winching up a hydrophone

Soon our time was up, our equipment loaded onto LABRADOR and its course set for Resolute. After lightering off our gear at Resolute, our thanks and good-byes over, we stored our tractor and wannigan in an MOT garage and packed the rest for shipment back to PNL for refitting and use in our next Arctic field trip in the spring of 1962. We arrived home in late September via a C130 flight to Namao, Alberta, and commercial jet to Victoria with a good six months' data analysis ahead of us.[6]

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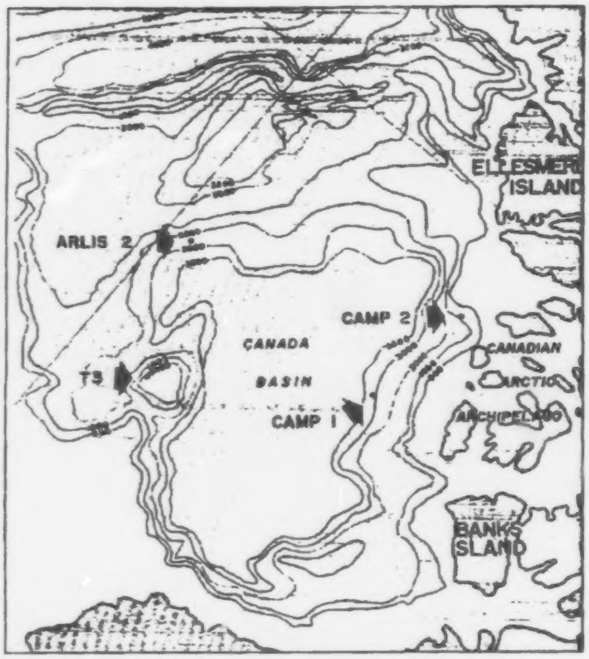
[6] A.R. Milne, "Acoustics Under Arctic Sea Ice: M'Clure Strait, August-September, 1961," *Defence Research Establishment Pacific Report 63-1*, (January 1963).

Arctic Ocean, April/May 1962, 'Polarpack 1'

Planning for work in the Arctic Ocean Basin



Arctic Ocean Sites in *Polarpack 1*

During the previous years, I had developed contacts with the US laboratories engaged in Arctic research, in particular with scientists at the US Navy Electronics Laboratory, the General Motors Defence Research Laboratories (now disbanded), the US Naval Ordnance Laboratory, and the US Navy Underwater Sound Laboratory (USNUSL). Individuals such as H. Kutschale, H.W. Marsh, R.H. Mellen, Alan Beale, and W.K. Lyon were using ice islands *T3* and *ARLIS 2* as platforms for conducting a variety of Arctic studies. The problem with ice island platforms is that their locations depend both on where they were discovered and on their drift with the surface currents of the Arctic Ocean Gyre. Some island-to-island under-ice acoustic propagation experiments had been done using narrow bandwidth sound projectors but these were of limited applicability to the problem of passive detection of submarines.

To remedy the limitations of that work, Alan Beale, of USNUSL, and I proposed to detonate underwater explosives, as broad-bandwidth sources, at the ice islands and at three icecamps to be established by PNL. Depending on logistical limitations, the PNL camps were to be located at the edge of the Canada Deep to ensure that the explosive sounds would propagate through deep water between the icecamps and the two ice islands. This proposal generated immediate support from Trevor Harwood of DRB's Arctic Research Group and was approved in principle by DRB/HQ. Trevor was aware that the Air Forces would be providing two DC3 aircraft to support an April 1962 Canadian Army field exercise conducted from the weather station at Mould Bay, on Prince Patrick Island. He therefore proposed, and I agreed, that the DC3s be positioned at Mould Bay in advance of the Army's requirements to establish and support one of our icecamps on the Arctic Ocean. At the time I wondered whether the air crew had ever landed a DC3 on a frozen lead and if they had experience in judging the thickness of the ice.

I then phoned Fred Roots, the director of the Polar Continental Shelf Project (at that time still based at Isachsen), to see whether he would be able to assist us in establishing a second icecamp on the ocean north of Ellef Ringnes Island in early May. I also requested the use of a Polar Shelf helicopter so that we could conduct a short-range explosive-sound propagation test from this second camp. Good old Fred came through again and agreed to give us what we wanted. Trevor then made the necessary requests to the RCAF for C130 Hercules airlifts from Namao to Mould Bay and return and between Mould Bay and Isachsen. Clearly, our project proposal had gelled although limited to two icecamps.

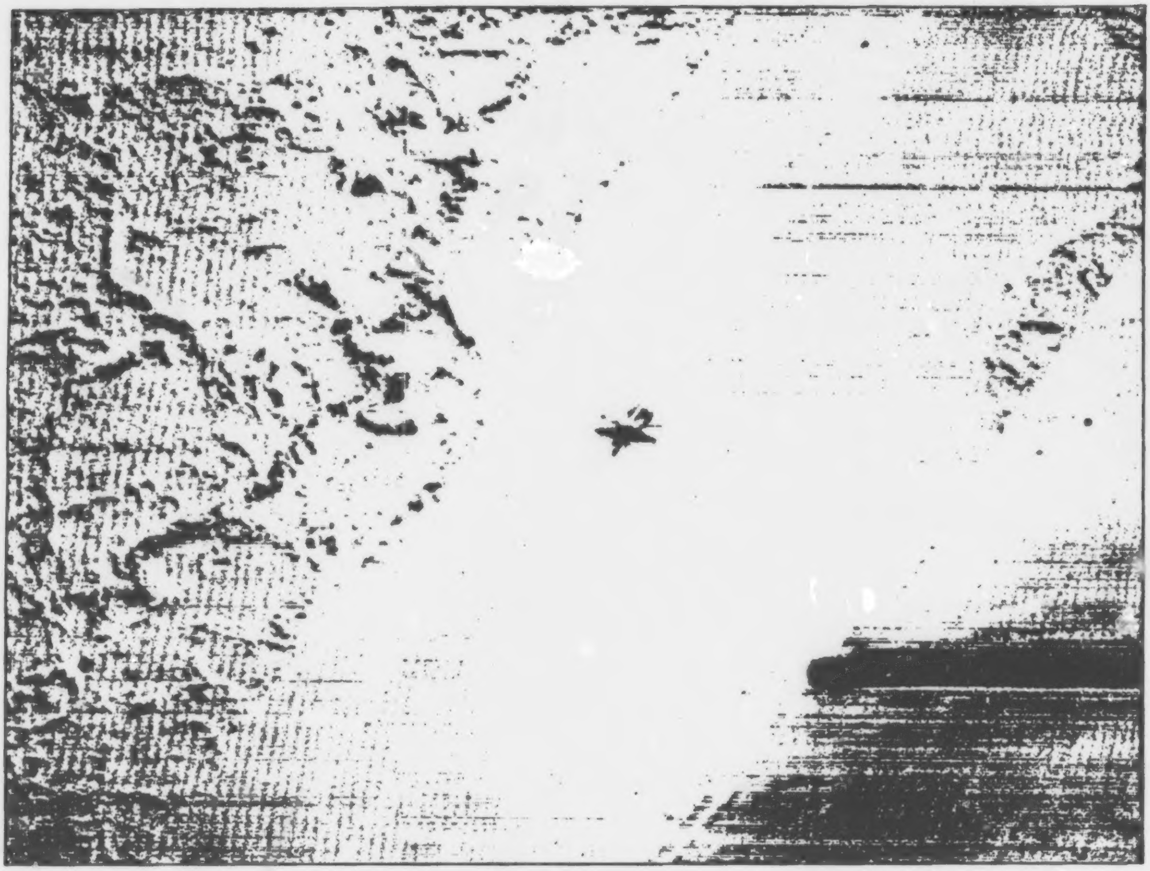
Our field crew included Tom Hughes, John O'Malia and myself from PNL, and Dick Herlinveaux, again seconded to our project from the Pacific Oceanographic Group. This was to be our first field trip to be solely aircraft supported and required some different equipment. Graeme Dennison designed a light-weight fabric shelter to suit our new mode of transportation. It was made in two parts, each with an insulated floor, each part doubling as a packing crate. The shelter skin, sewn together in the Dockyard sail-loft, was double-layered life-raft fabric with Dacron pile between the layers for insulation. Supporting the fabric were aluminum tubes, bowed to be assembled in Gothic arches and designed to be inserted in ridge tubes. Zippered entries were at both ends of the twenty foot long shelter, which was spacious enough to sleep four on the floor, and include a 'kitchen box,' a space heater with a snow melter, and the all important electronics. Explosives were ordered and shipped in advance to Mould Bay and Isachsen on early resupply flights. We could draw on gasoline and kerosene stores, in ten gallon drums, at both locations. Field rations, a 303 calibre rifle for protection from bears, and all other stores and equipment would be flown north with us. Radio communication procedures between PNL icecamps, Mould Bay, Isachsen, and the ice islands had been set up. We were ready to go on what proved to be the 'hairiest' field trip by far.

Polarpack 1 field work

The C130 Hercules thumped down with a roar at Mould Bay in a cloud of dust and snow as the propellers reversed their thrust. The early April temperature was -35°C as we assisted the loadmaster to slide our cargo off the rear ramp onto a truck. We noted the two DC3s parked nearby. Our gear was temporarily stored in an MOT garage, after which we introduced ourselves to the station manager, were assigned bunks, and then conferred with the DC3 aircrews.

DC3, ski equipped for Arctic operations

They had no prior experience of landing on frozen leads so we devised a procedure for landing on what may be a suitable lead. Both DC3s were equipped with skis, and with wheels protruding beneath them, to take care of either deep snow or smooth ice. It was decided that the two DC3s would accompany each other; the first, lightly loaded, would attempt a landing on a visually acceptable lead only after an expendable ten-gallon drum was flung out onto the lead from a height of several hundred feet. If it stayed on top of the ice, then several rolling passes would be made to further assess the weight bearing capacity of the ice. Also, John O'Malia and I would leap out from the slowly moving aircraft and quickly drill a hole while it flew around again. Three-feet plus of ice would yield an affirmative wave from me, then both the first aircraft and the follower, with Tom, Dick and our camp equipment, would land. If the first aircraft broke through the ice despite our precautions, the one in the air would be able to initiate a rescue operation with the aid of Polar Shelf helicopters.

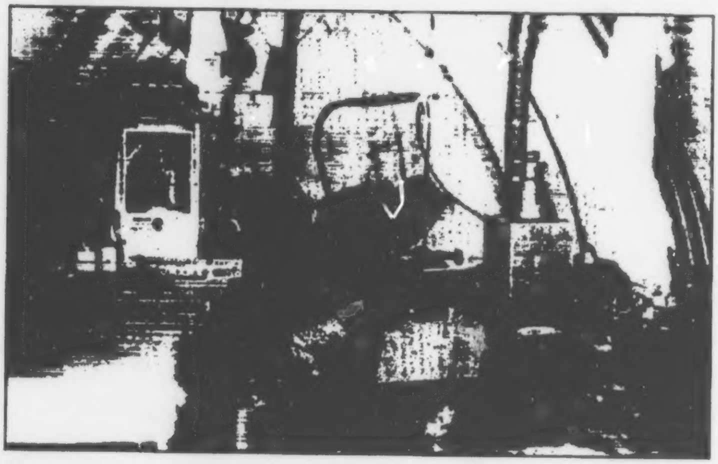


Landing of DC3 on frozen ice lead being observed from accompanying DC3

First we had to test our re-designed drill bits. The station manager drove us in his ancient, growling snowmobile to a frozen lake on the other side of the runway past where the army's supplies were stacked. Two Arctic wolves were busy tearing apart a wooden crate of butter. They were taking turns swallowing whole, hard-frozen pounds of butter! They paid no attention to the vehicle but scattered when we stepped outside.

The weather forecast was good and after loading most of our gear on one DC3, we set out in the two aircraft on a roughly WNW course from the north tip of Prince Patrick Island. We had to travel at least a hundred miles offshore to ensure that we could locate a camp over the edge of the Canada Basin. A great many frozen and open-water leads were seen en route all aligned with the numerous shear-boundaries between the moving offshore ice and the sporadically fixed shoreward ice. Suitable leads were rare—some too short, some too twisted and narrow, some dark and obviously too thin, and others with ice shards embedded in them. Finally, 370 km from shore, we found a candidate lead. It was smooth and had at least a 3,000-ft landing space but it was suspiciously smooth. (An old, thick lead is usually covered with low snowdrifts indicating a lapse of time necessary to grow thick ice.) We pushed out the ten-gallon drum. It stayed on top. After several low passes, we touched down, the pilot purposely bouncing the aircraft and rolling slowly before taking off again. One more observational pass preceded another landing and slow taxiing. At this point, John and I leaped out with our chain-saw, engine driven drill, and hastily drilled a hole through the ice. Hooray, it was 3½ ft thick! With a feeling of relief I waved in our pilot. Soon we had our camp set up at the edge of the lead on thicker ice. We set up and tested our LF homing beacon and also tested a miniature UHF beacon, supplied by the pilot. We said our good-byes to the aircrew, and they touchingly assured us that they could find us. The cellular telephone-sized beacon was used to home in on us later on that vast, white ocean.

After Tom had cooked a quick meal and our camp was made weather proof, a hole was drilled and blasted through the ice for access to the ocean 2,700 m deep beneath us. We were separated from it by a thin, fragile sheet of ice and we were constantly aware that a hurried move to safer ice might become necessary.



Tom Hughes in our home on the ice over water 2,700 metres deep

Al Milne taking water samples

We communicated with ice islands *ARLIS 2* and *T3* to alert them that our camp was in business. With our radio links established, we recorded the sounds that travelled under the ice from the ice islands when they detonated 50-lb TNT underwater charges. At our end, we set off 16-lb Nitrone underwater charges, their sounds being recorded at the ice islands. The travel-times of the explosive sounds indicated that our distance to *ARLIS 2* was 1,150 km and to *T3* was 1,000 km. Over such long distances, the sounds consisted entirely of frequencies less than 50 Hz. They were also of more than eight seconds duration having suffered many reflections from the very rough underside of the sea ice as they propagated through the 3,500 m deep Canada Basin. Between times, Dick was assisted making hydrographic bottle casts and we recorded underwater ambient noise. An innovation on this field trip was the inclusion of a 'ham' radio transceiver. We were able to phone patch to our homes through the 'ham' radio operated in the evening by Robbie Robson at PNL—a great morale booster!

I called Mould Bay to get us picked up by the DC3s and they were happy to comply since they had to get on with their commitment to the Army. Soon we were back at Mould Bay waiting for our C130 Hercules to take us to Isachsen on Ellef Ringnes Island. After two days of pure luxury in the lounge at the Mould Bay weather station, we landed at Isachsen ready to set up our second icecamp on the Arctic Ocean. Fred Roots quickly organized our transportation to the offshore lead being used to resupply an existing Polar Shelf hydrographic base camp. This was located 145 km WNW of Ellef Ringnes Island over water 550 m deep on the continental slope, and suitable for our purposes.

Tom Hughes filming the welcome arrival of our DC3 returning to Camp 1

After two flights in a 'Single' Otter, our camp was set up and we proceeded initially to operate as we had at camp 1, receiving and sending explosive sounds from and to the ice islands. One evening, the nearby Polar Shelf camp was invaded by a hungry polar bear who pulled a sleeping hydrographer from his tent and dragged him off over the bumpy ice in his sleeping bag, that is until a buddy killed the bear with a well placed rifle shot. He was understandably upset but unharmed.

Our work with the ice islands was soon over. I then called up Fred and requested the promised helicopter support, and shortly afterward, an Otter bumped down and dumped a load of turbo fuel, followed by a Bell 204B helicopter to assist us with our short-range sound transmission test. The pilot and his mechanic stayed and ate with us. It was cosy on the floor of the shelter with six bodies sleeping head-to-toe like sardines in a can.

The next day, Dick Herlinveaux and I loaded our explosives, drilling gear, 'det' winch, firing box and radio on the helicopter and we headed further offshore over increasingly deep water to stop at intervals to set off our underwater explosives. We sought open water cracks between floes to minimize drilling, and positions were logged on the helicopter's Decca receiver. Meanwhile, John and Tom waited at the camp for our alerting radio messages that shots were ready and to start recording. As we got more than 20 km to the northwest our radio messages fizzled into nothing. Dick and I decided to carry on to set off shots to a distance of 90 km, hoping that Tom would record the hydrophone's output almost continuously, which he did. Our gamble paid off as related in the following doggerel I composed for Tom's retirement party:

The Ordeal of Arctic Tom

It's true we'll now regret this day
when Tom has gone and has no say
on how the packing should be done
and making sure that things do run.

The Arctic will not be the same
with Tom not there to guide and tame
young scientists with wild ideas
to try out on the frozen seas.

Not many of you know this tale
of how Tom stays so young and hale
but let me tell you how it went
one springtime in an Arctic tent.

Our camp was set upon the pack
two hundred miles when you look back
to shores and islands of our land
so far removed from sun and sand.

Aboard a 'chopper' Dick and I
set off toward the Northern sky
complete with drills and 'dets' and shots
to ice where maps were marked with spots.

Back at the camp Tom was alone
while 'neath the ice a hydrophone
was lurking ready for the sound
and tape recorders were rewound.

The radio was crackling loud.
His brow was like a thundercloud
as strain he might the voice to hear
to tell him when the shot was near.

Had the ether masked the voice?
and will I not have any choice?
except to drain the battery pack
and run the tape recorder slack?

Minutes later, ten went past.
It seemed the tape would never last
but then the shot came rumbling in
and filled the tent with such a din!

He punched the switches off with haste
and rushed outside - no time to waste
refuel the stove - melt some snow -
recharge the cells - keep on the go.

The hours came, the hours went,
within that beehive of a tent
which perched upon the moving ice - that
groaned and creaked and squeaked like mice.

The guessing game continued on,
the scheduled timing long since gone
and still he fought with fervent hope
where lesser men would never cope.

Dick and I we felt like fools,
to rush so much with frosty tools.
Our radio 'twas sad to say
might live to work another day.

We hastened South aboard our bird
with little chance our shots were heard.
With beacon on we homed right in
and there was Tom. He wore a grin!

The tapes were boxed, all neatly so.
The batteries charged, all in a row.
But that's not all, there was a pot
and Tom said "Quick, while it's hot!"

He'd fixed some mush for us to eat
We thought it was a special treat.
But then I knew, the thought did rush,
the elixir of life is mush!

And now you know why he's so spry;
he yearns for mush and not for pie!
It's plain and natural one might say
for humans like a horse with hay!

It's true we'll all recall this day
when Tom has gone upon his way.
But then the memories of the past
are treasures that will last and last.

We completed our work,[7, 8] packed up our camp into two Otter loads, and flew back to Isachsen to wait for a C130 airlift home.

A visit to ice islands Arlis 2 and T3 and other places

The homeward journey from *Polarpack 1* became suddenly more complex—two of us had an invitation to visit ice islands *ARLIS 2* and *T3* with Fred Roots. Tom and John opted to return to Victoria with our cargo on the C130 while Dick and I travelled with Fred, on a Polar Shelf chartered Beachcraft, for a first stop at the Arctic Research Laboratory (ARL), in Barrow, Alaska. We visited their several research sites; the one that impressed me the most dealt with permafrost. They had drilled a series of one-m diameter, 25 m deep holes vertically into the permafrost using a very large industrial auger. Lights were strung down one hole and I was invited to descend down a ladder for a look. It was all ice, except for a few tufts of vegetation not amounting to much. I was visually reminded that if all the permafrost should melt, Barrow, and a good fraction of Northern Alaska would be several hundred metres beneath the sea.

We had time to snoop around Barrow village, visit the Eskimos and see Will Rogers' memorial headstone at the desolate edge of the Arctic Ocean. The next day we got aboard a stripped-down, rattling DC3 and headed northward to visit the ice islands. *T3* was a large piece of 18 m thick glacial ice originating from the Ward-Hunt ice-shelf off the north end of Ellesmere Island and had drifted to the western edge of the Canada Basin. It had lost about 2 m of thickness during the summers it had roved westward, leaving a crashed DC3 perched on an ice pedestal preserved in the shade of the aircraft's wings. We were introduced to the people whose voices we knew over our radio and shown their projects under way. After a luncheon, we headed for *ARLIS 2* located at the far side of the Canada Basin, 1,100 km offshore of Barrow. In contrast to *T3*, *ARLIS 2* was a very large, bumpy old floe thought to be shelf-ice transformed over many years of summer melting and winter growth into 'paleocrystic' sea ice some 6 m thick.

After an all too brief visit, we departed for the long flight to ARL at Barrow and the next day left aboard the Beachcraft for Yellowknife, on Great Slave Lake. We landed on Shell Lake covered with 10 cm of melt-water and sloshed in our water-filled mukluks to shore carrying our town clothes, then hailed a taxi to stay overnight in the dingy Yellowknife Hotel. A chance meeting with the local director of the Department of Indian Affairs and Northern Development got us a dinner invitation to his home where we dined on caribou with his family. In the middle of dinner, a fire alarm siren sounded accompanied by nearby commotion. Dick squirmed in his chair and then burst from the room, grabbed his parka, and ran to the fire. Shortly he returned, glowing with pride saying, "I showed them how the Nanaimo Volunteer Fire-fighters get the job done properly!" Our next stop was at Uranium City, on Lake Athabaska, Saskatchewan, where McMurray Air Services, the main air service contractor with the PCSP, had their base. From there we flew to Edmonton, where we left Fred Roots and caught a PWA flight to Vancouver, then to home.

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[7] A.R. Milne, "A 90-km Sound Transmission Test in the Arctic," *Journal of the Acoustical Society of America*, Vol. 35, No. 9, 1459-1461, (September 1963).

[8] A.R. Milne, "Sound Propagation and Ambient Noise Under Sea-Ice," in V.M. Albers (Ed) *Underwater Acoustics*, Vol. 2, Plenum Press, New York, 1967, pp 103-138. Presented at the Advance Study Institute on Underwater Acoustics, Copenhagen, (25 July-5 August, 1966).

Prince Gustaf Adolph Sea, February 1963, 'Icepack 3'

Preparing for mid-winter field work out of Isachsen

Following *Polarpack 1* in the spring of 1962, John Ganton became interested in relating the many unusual features of under-ice ambient noise to their physical causes and hinted that he should get some first-hand experience in field work. Similarly, Ray Brown got involved in analysing the nature of explosive sounds backscattered from under sea ice, and in doing so wanted to get into the Arctic. I was delighted, and promptly got their willing participation in the planning and execution of *Icepack 3*, to take place in the frigid, winter gloom of February 1963. Our field crew would consist of John Ganton, Ray Brown, John O'Malia and myself. The main purpose of *Icepack 3* was to record ambient noise under polar pack-ice in the absence of solar heating changes, and to examine its directional characteristics.

Again, we were to get Fred Roots' support out of the Polar Shelf base at Isachsen, although it would be nearly shut down in February awaiting an influx of investigators in the spring. He would provide our various fuels in ten gallon drums; we could use his garage facilities, including their Nodwell tracked vehicle; we could get help from his skeleton staff including the provision of meals, and be able to bunk down in one of his Parcol huts. Also, the MOT weather station agreed to monitor our radio communications. To round out this multi-service support, the RCAF would provide us with special C130 Hercules flights directly to Isachsen from Victoria Airport and a return flight, on demand, on completion of our field work.

Much of our heavy field equipment was already lurking in the snow at Isachsen. One of our J5 tractors would be revived to pull a wannigan used to house our electronics. We planned to use Polar Shelf's large, Nodwell tractor to carry a load of boxes and to pull a loaded Norwegian sled. The folding fabric shelter—employed on *Polarpack 1*—would be used to house and feed our field party. Although Tom Hughes was not to go on this trip, he and Frank Greensmith worked diligently preparing and packing our revised instrumentation, packaging our food in 'dry ice,' and carefully listing the contents of our many, numbered, snow-proof boxes. I anticipated that we would have to work in temperatures as low as -50°C, and at times with high winds. My previous experiences using the army-issue parkas and wind-pants showed that they would not allow us to function for much time under such severe chilling conditions. Consequently, I set about exploring for alternatives, which culminated in the development and construction in Victoria of unlined parkas and wind-pants using L19 Ventile cloth manufactured in Britain for the British Antarctic Survey. Ventile cloth is almost impermeable to air but is permeable to the water vapour produced by an active person, a property desired for keeping inner garments dry. Separate inner liners were made of knitted nylon fleece.[9]

To thread several hydrophones through thick polar ice, using nine-inch diameter drilled holes, is a much more appealing prospect than lowering them through holes blasted with explosives, the latter requiring much pre-drilling and explosives to be safely shipped. To keep the holes from freezing closed, John had the Dockyard life-raft shop make nine-inch diameter, inflatable, rubberized fabric tubes. While flaccid and weighted, they could be stuffed down drilled holes once the hydrophones and their cables were in place and then inflated to eject the sea-water. Failing the success of John's idea, we would have to rely on regular chiselling of the ice as it formed and frequent rescuing of hydrophones.

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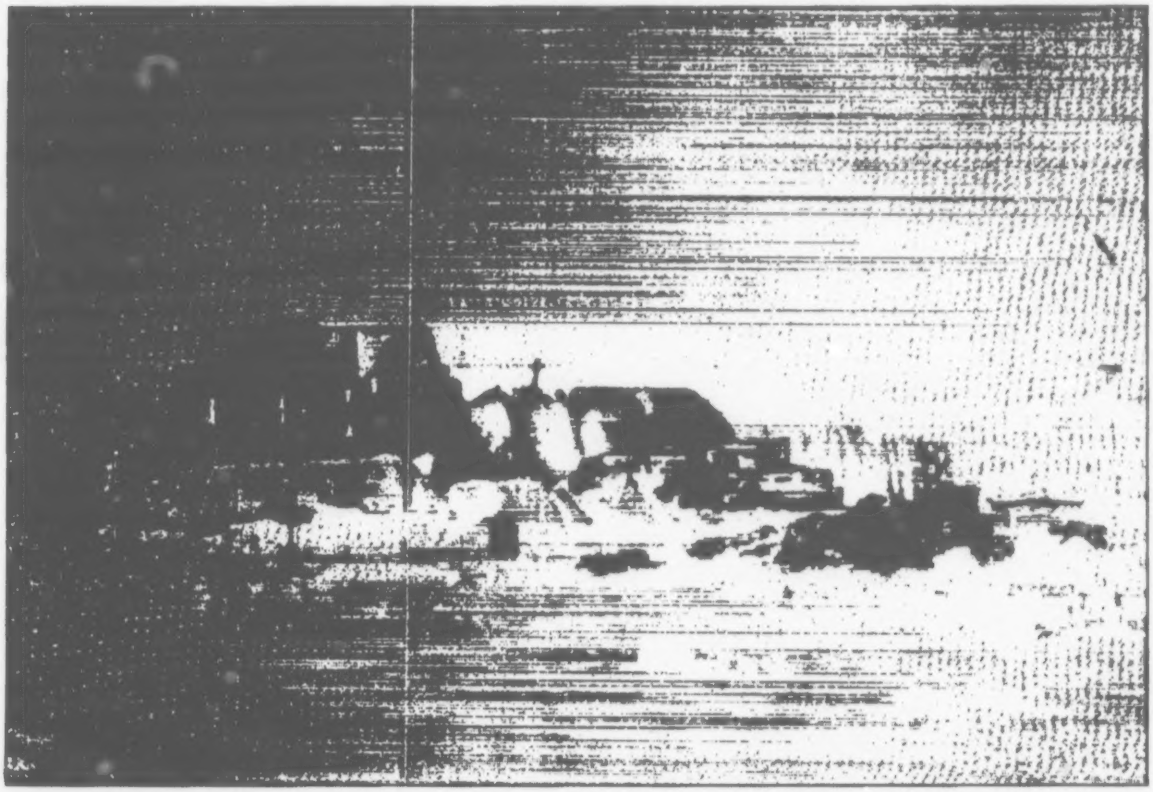
[9] A.R. Milne and E.L. Lewis, "Field Trials of Icepack 3 Arctic Clothing," *Pacific Naval Laboratory Technical Memorandum 63-7*, (August 1963).

By now you would think that everything would have been thought of and nothing would be missing. We forgot ash trays and no-smoking signs! Ray was a smoker then, but vowed to give it up immediately after this trip, partly because of being jibed about his incessant scattering of ashes in the shelter, but mostly because of smoking-induced circulatory restrictions which caused his feet and hands to be unduly sensitive to the cold.

Icepack 3 field work

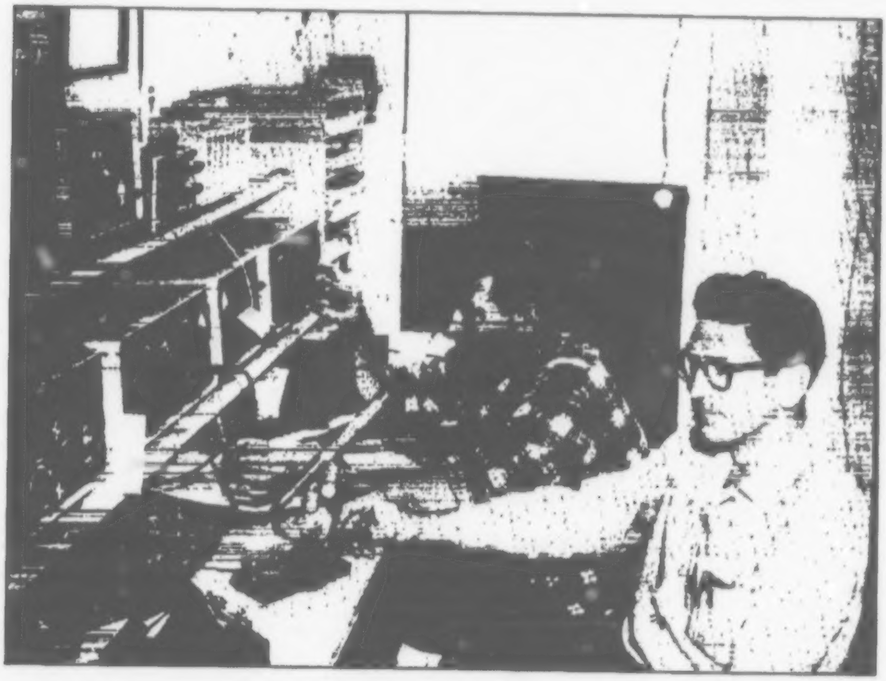
On a drizzly 24 January, we roared out of Victoria Airport in the RCAF's Hercules on our way to Isachsen. On this flight we wore industrial-grade 'ear defenders' to make the horrendous noise in the cargo area tolerable. Nearing Isachsen, we donned our flashy new orange-coloured Arctic clothing ready to disgorge our cargo, mostly a multitude of boxes, antenna poles and survival gear. Yvon Perron, Polar Shelf's driver-mechanic, arrived in their Nodwell tractor to move our cargo to the Polar Shelf camp. It turned out that Yvon was to attach himself to our expedition, not only to drive the Nodwell but to assist us in any way he could. He was an extremely resourceful and willing person.

Five days after arriving, we got our tractor train underway, the loaded Nodwell pulling a cargo sled and the J5 pulling the instrument wannigan on a sled. There was no stopping planned as we meandered offshore in the darkness through a fortuitous gap in the huge shore pressure-ridge, then over rough, polar ice similar to that encountered in *Icepack 1* in the spring of 1961. There was no exploration of a route on foot since visibility depended on the head lights of the tractors. Then we were abruptly stopped by an insurmountable, gapless pressure ridge



***Icepack 3* camp in the Arctic night**

that I surmised was strung between the headlands defining Deer Bay. Also, one of the runners of our two Norwegian sleds was seriously damaged by this time, so we could go no further. After what seemed an interminable night, we got our shelter up on a flat, frozen lead and its stove going. When snow was melted for water, a much-needed dinner was prepared. After the cargo was unloaded, all the boxes were placed in a line, the radio antenna was erected and radio contact was made with MOT. After a 'night's' sleep and breakfast, Yvon left for Isachsen, a slow two-hour trip following our previous tractor tracks to bring back tools and materials to repair the damaged sled runner. Meanwhile the rest of us got the camp organized to achieve what up to this time was a paper scientific plan. The -45°C of the Arctic night gives one a brutal reality check. Fumbling in clumsy mittens and breathing clouds of fog slows work to a snail's pace. Yvon returned two days later and set about repairing the damaged sled.



Robbie Robson and Ray Hale manning the PNL communication centre

Our first hole drilled and the hydrophone and its preamplifier threaded through the hole and lowered 100 m to the bottom, John and I tried out our inflatable hole preserver. As it was being inflated, it would try to emerge from the hole like a grotesque sausage and had to be subdued with the weight of a 10 gallon drum. So far, so good. We completed installing the other two hydrophones all separated horizontally by 100 m at the corners of a square. Our anemometer and air temperature gauge erected and batteries charged, we set about making periodic tape recordings of under-ice noise, wind speed, and air temperature. As usual, we all took turns with the chores. There was cooking and washing up; refuelling the generator, the lamps and stove; checking the hole-preserver's inflation; and making recordings. The important 'biffy' was constructed and John's fur-lined toilet seat installed. John, a long time radio man, would phone-patch us through to our families via Robbie at PNL. We got to know a great deal about each others' personal lives on the ham airways!

One night we recorded 80 mph winds. The floor of the shelter, attached to the fabric, began to lift with wind gusts. Like a sailboat close-hauled, we had to sit on the upwind side of the shelter to keep it from capsizing. Then, as if this was not enough, the wind caused a blow-back in the smoke pipe of our kerosene-fuelled stove and flames belched out of its air intake. Smoke filled the shelter as wind pressure threatened to blow it over. There was an instinctive rush to get outside—we were all suited-up in our sleeping bags when the storm became more threatening. I yelled 'hold it,' then cracked open the zipper of the upwind hole used for putting snow blocks into the melter. The stove sucked in its errant flames as the air pressure increased in the shelter, and with relief we began to breath the fresh air. We got little sleep that night until the wind subsided.

After we rolled out of our sleeping bags and twilight returned, Yvon exclaimed, "I'll fix that damned smoke pipe!" He cut up empty oil cans and made an 'H-top' which he assured us would prevent any future blow-backs. Never did we go without 'H-tops' thereafter! Knowing now that snow piled on the skirts of the shelter would not hold it down in a storm, we jury-rigged rope tie-downs from the ridge of the shelter to pegs secured in holes drilled in the ice. I was first to the biffy and froze my bottom to the fur on the toilet seat which by now was permeated with snow. However, there was no permanent damage.

By this time a huge, black Eskimo dog called Boots had attached himself to our camp. This critter became an almost intolerable nuisance as it migrated between the Polar Shelf kitchen and our camp begging for handouts at both ends of the 25 km route. It had learned to use its nose to open the zipper entry into our fabric shelter, never respecting the time of day or night!

Our work completed and data preserved on tape,[10,11] it was time to deflate the hole-savers and hoist up the hydrophones. Sad to say, one air bag had deflated, allowing the intruding sea to freeze a hydrophone's cable in an unyielding grasp.

Before the final packing could be done, the tractor engines had to be started. First the Nodwell. Its warmed battery was installed and paralleled with the J5's battery, and after a generous squirt of ether aerosol was sprayed down its air intake, it groaned fitfully to life. Starting the J5's engine was delayed since the storm had filled its engine compartment completely with hard-packed snow. (The Nodwell's engine compartment was open underneath which allowed the snow to fall through). After hours of fighting with the vicious vehicle, it decided to give in and go to work. Although difficult to service, servicing was not the most serious problem we had with J5s. When towing, they were prone to becoming 'belly-beached' on snow drifts with their too narrow, short tracks futilely flailing in self-made trenches. I therefore promised myself that if we were going to do similar field operations in the future, we must improve on the J5s, and—it goes without saying—the sleds.

At Isachsen, we readied the J5s, and the wannigans and sleds, for shipping and storage at Resolute; the shelter and remaining cargo accompanied us to Victoria in anticipation of the next year's field work.

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[10] A.R. Milne and J.H. Ganton, "Ambient Noise under Arctic Sea Ice," *Journal of the Acoustical Society of America*, Vol. 35, No. 5, 855-863, (May 1964).

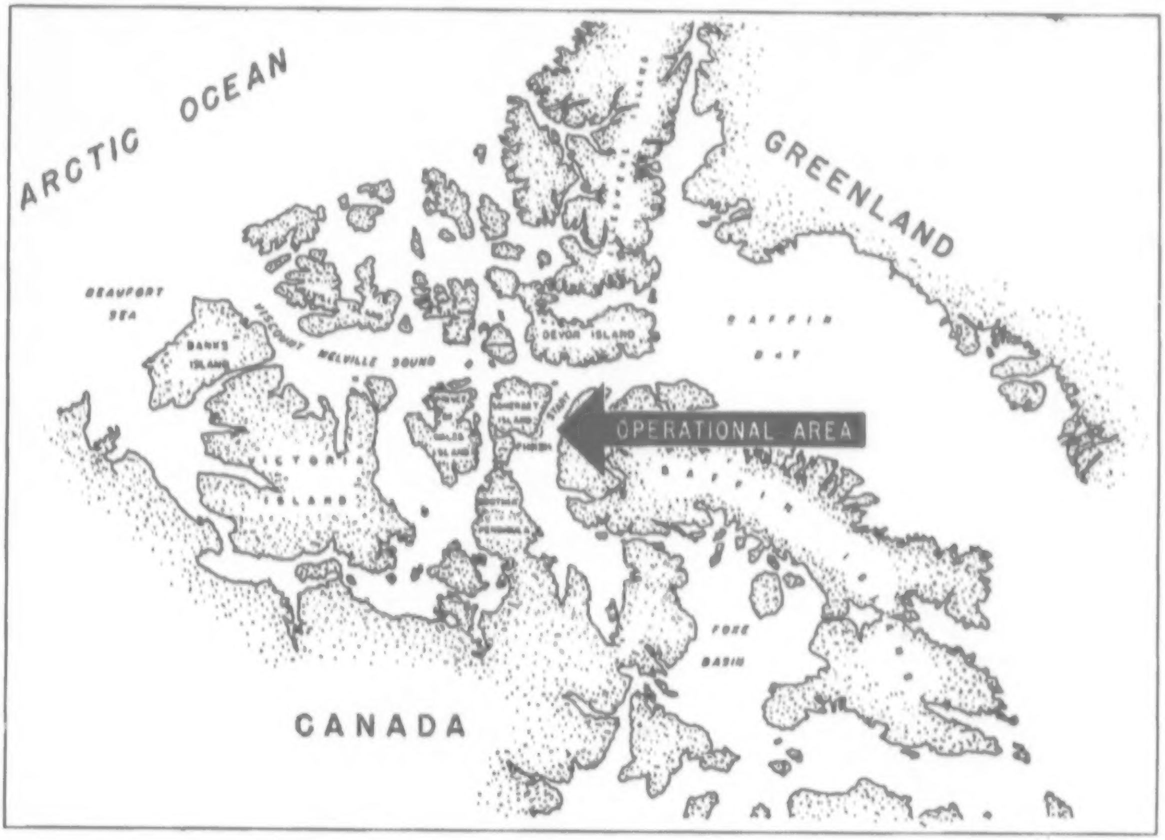
[11] A.R. Milne, "Underwater Back-scattering Strengths of Arctic Pack Ice," *Journal of the Acoustical Society of America*, Vol. 36, No. 8, 1551-1556, (August 1964). Note: Later analysis revealed a likely 17 dB calibration error. J.R. Brown and A.R. Milne, "Reverberation under Arctic Sea-Ice," *Journal of the Acoustical Society of America*, Vol. 42, No.1, 78-82, (July 1967).

Prince Regent Inlet, August 1963, ' Icepack 4'

Preparations to record reverberations under summer sea ice

Ray Brown's taste of the Arctic in February on *Icepack 3* did not deter him from planning a summer's adventure using an icebreaker. The Arctic Research Group in Ottawa arranged for Ray's PNL party to be flown to Resolute to meet the icebreaker CCGS JOHN A MACDONALD, after its summer re-supply escort duties. The plan was to seek suitable ice in the Arctic Ocean from which to make the reverberation measurements needed to supplement the sparse data in the literature. To do this, the icebreaker would have to push its way westward through Viscount Melville Sound and M'Clure Strait and pass by Prince Patrick Island into the Beaufort Sea. Ted Fleischer arranged for a hydrographic winch to be on board for Harry Hollister to take bottle casts. He was seconded to the PNL party from the Pacific Oceanographic Group. Tom Hughes, John O'Malia and Dave Street made up the rest of PNL's field crew.

Our well-used tent shelter would house the electronics and house-keeping gear all shipped from PNL. Food would be supplied by the icebreaker. Explosives were ordered from CIL, James Island, and shipped in advance to Resolute. Our eager PNL crew arrived in Resolute on an RCAF C119 'flying box-car' on 23 August to find that no arrangements for accommodations had been made. Sleeping space was eventually found and they had to wait eight days before the CCGS JOHN A MACDONALD arrived. Long waits in Resolute are a boring

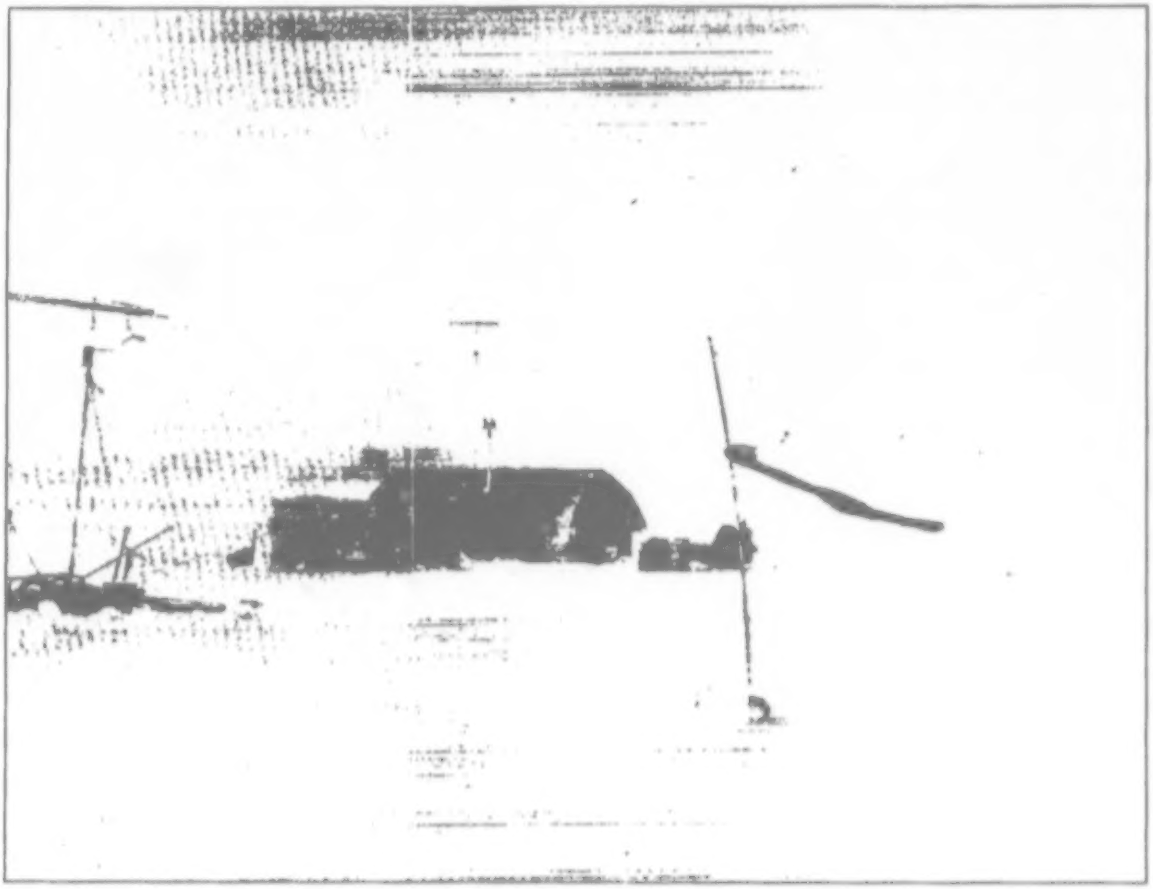


Location of *Icepack 4*

experience! Finally, on 31 August, it anchored in the brash ice of the bay at 1700 hr. The cargo was lightered and hoisted aboard while our gallant PNL crew were helicoptered out to the ship which got under way by 2100 hr.

Hopes for much field work seemed dim

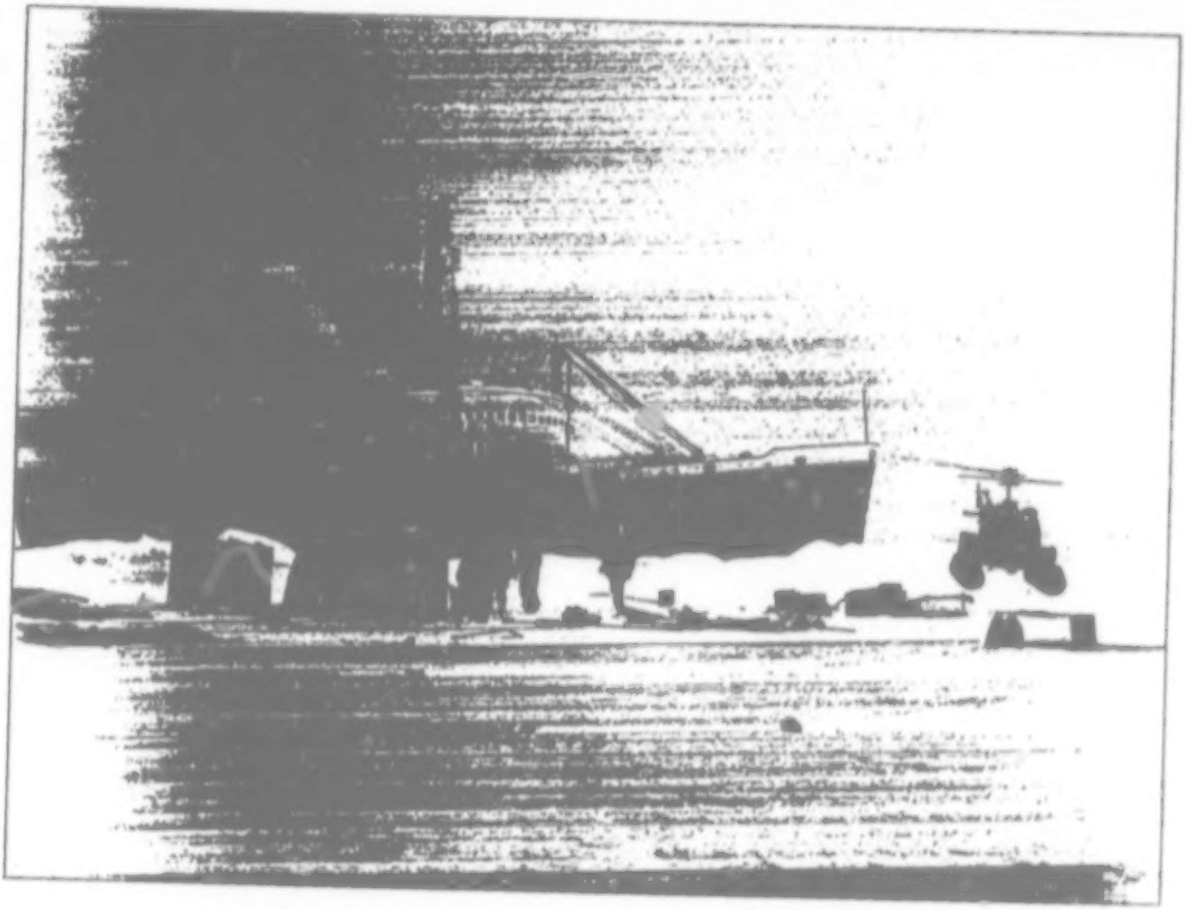
Captain Cuthbert informed Ray that it was his last command before retiring and although he wanted to sail westward through the Northwest Passage, he would have to round Point Barrow, Alaska, by 15 September to avoid being locked in for the winter. This date restriction reduced the likelihood of having more than a few days in the Beaufort Sea to allocate to PNL's on-ice program. All was not lost, however. The ship was rebuffed by very heavy polar ice which had drifted south into Viscount Melville Sound from channels to the north, this drift being attributed to an unusually warm summer. Then, turning eastward, the alternative plan was to find continuous ice cover over water more than 200 m deep. Suitable ice was found in Prince Regent Inlet, south of Lancaster Sound, between Somerset Island and Brodeur Peninsula, over water 275 m deep. Quickly the camp was set up, holes were drilled for the hydrophone and explosives, shots were fired and recordings made. To save time, hot meals were delivered by the ship's Bell 206 helicopter and at the day's end, the PNL crew was flown back to the ship for



***Icepack 4* camp**

dinner and to stay over night. After three days, the skipper told Ray to pack up quickly—the ship's doctor was deathly ill and had to be taken to Resolute. The icebreaker drove alongside the icecamp and a half hour later the camp was on the ship, which then crunched its way to Resolute arriving at 0400 hr on 9 September. The adventure ended with the ship's planned "Transiting the NW Passage party" taking place in Resolute's harbour.

Ray left behind in Resolute the tent shelter, the design of which had generated some interest in Defence Headquarters, apparently stimulated by Cdr Jim Croal who had been with us on *Paclabar* in 1959. Jim wanted to use it on the ice of Resolute harbour the following Spring. With the shelter came its stove, fire extinguisher, snow melter and a couple of ten-gallon drums of kerosene stove fuel. Then in April 1964, Jim set up the shelter and went back to Resolute to bring out guests to occupy the shelter, meanwhile leaving it with the stove on to make it cozy. Disaster struck! Upon arriving at the camp site, all that was left were charred ruins. That must have been mortifying for him as reflected in an unapologetic letter to PNL castigating the designer for constructing such a flammable shelter. According to unnamed witnesses, the drum of stove fuel had been precariously mounted on snow blocks against the shelter to provide the necessary gravity feed to the stove. The drum had evidently slumped, enfolding the shelter's fabric onto the stove. I regretted the loss of some interesting rhymes inscribed inside that shelter during idle hours in the past.

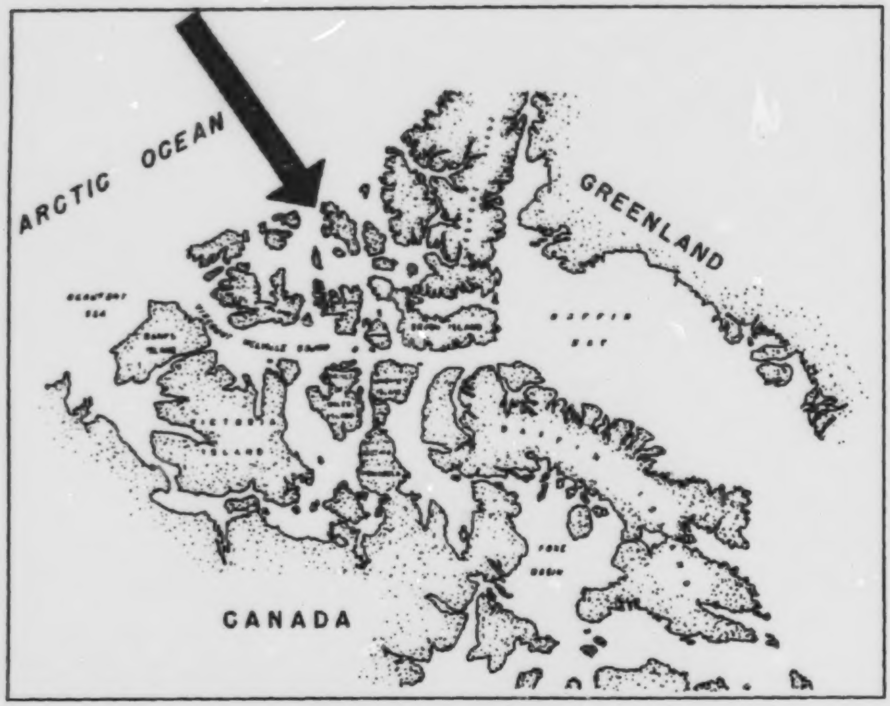


MACDONALD setting up icecamp in Prince Regent Inlet

Prince Gustaf Adolph Sea, January/February 1964, 'Icepack 5'

Preparing for our third field trip to Prince Gustaf Adolph Sea

As John Ganton and I began to unravel the puzzles of how noise under polar pack-ice is generated, more questions begged for answers. We soon began planning for a return to Prince Gustaf Adolph Sea in winter with more comprehensive instrumentation to explore further the links between wind speed and under-ice snow-drifting noise, and between air temperature changes and ice-tension cracking. Also, we needed better tractors and sleds and new Arctic clothing to replace the design using the too-fragile L19 Ventile cloth.



Location of *Icepack 5*

At this time, in 1997, I must mention the unreserved support John and I received in 1963 from Harold Grant, my Section Head, and Fred Sanders, PNL's Superintendent. We must have seriously depleted PNL's budget when we got our two new expensive tractors, had sleds and Arctic clothing made and had two camper-type huts built to fit onto the tractors.

I ordered the tractors from Logan, Utah, a make similar to the low bearing-pressure tractors used for grooming ski-hills. They were modified to have blow-torch-type heaters inserted into their engine cooling systems and to use special Ni-Fe cold-weather batteries for engine starting. The huts, made by Caveman Campers in Victoria, had folding side-panels enabling the overall height of a tractor with its hut to be reduced to fit through the rear of a C130 Hercules aircraft. The two sleds, made of aluminum, were constructed by Yarrows in Esquimalt (at a loss, I heard). They had four independent-swivelling runners and wagon steering which provided enough flexibility to negotiate lumpy ice surfaces.[12]

We brushed up on our astro-navigation by practising to position Victoria correctly. Our positioning on the ice would depend on star shots and radio beacon bearings to Isachsen. We installed rotating flashers on top of the vehicles' cabs to use if it became necessary to find us by air.

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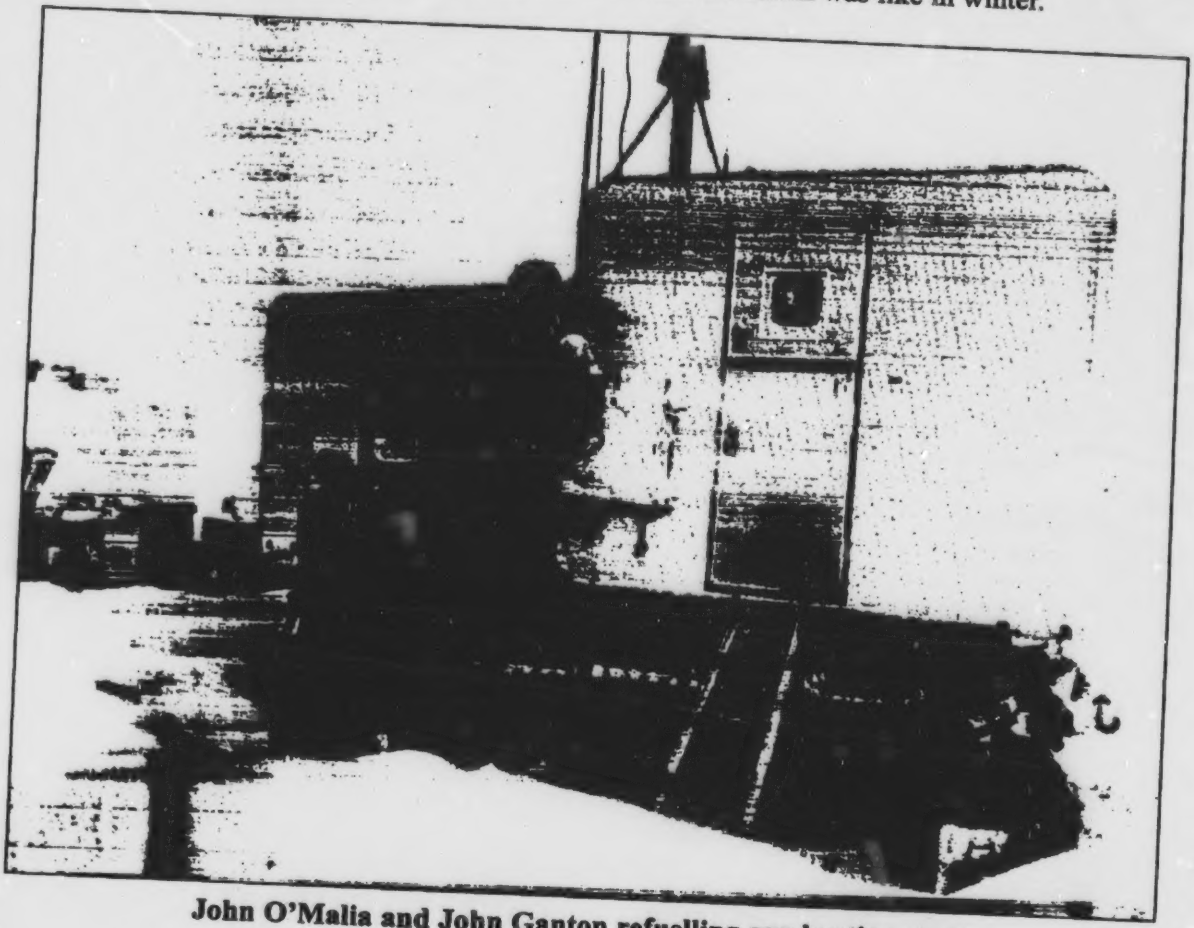
[12] A.R. Milne, "A One and One Half Ton Four-Runner Aluminum Cargo Sled," *Pacific Naval Laboratory Technical Memorandum 65-1*, (April 1965).

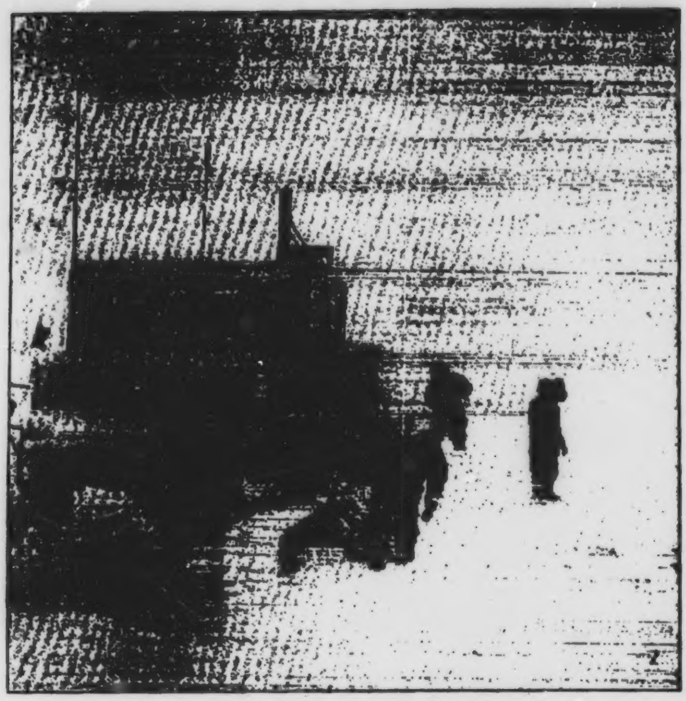
After the New Year, our frozen rations were prepared after wrangling about likes and dislikes with John Ganton. After talking with his wife, Doris, she recommended items that he would eat other than just cookies and milk! As on previous trips, our hydrophone cables were wound on separate winches which could be powered by hand or by using the hand-held ice-drill motor. The hydrographic winch was similarly powered. Tom Hughes, as usual, was chief packer and inventory lister, one of the many important jobs he carried out flawlessly. Finally we were ready. The C130 Hercules arrived at Patricia Bay Airport on 10 January and was loaded. Our families and some PNL people were there to see the action, and then we were airborne, headed for Isachsen. Don Gain, a science reporter for the *Victoria Colonist*, was also a passenger having requested passage to see for himself what the North was like in winter.



John O'Malia and John Ganton refuelling our heating stove

Our coldest field work

To quote Don Gain, "It was two weeks ago that I said good-bye to the four-man expedition at Isachsen, about 2,000 miles northeast of Victoria...." He then talked with John O'Malia at our field camp via PNL's ham radio. The time was 11 a.m. in Victoria, noon at the icebound camp. John told Don, "We are about 30 miles southeast of Isachsen; there is a faint glow in the sky. It hasn't been above 50 below since we left and the temperature has dipped to 65 below...."



The coldest work yet

After arriving at Isachsen, we picked up our fuels and explosives from the Polar Shelf cache, arranged for radio message exchanges with MOT, and were soon picking our way through the shore pressure ridge onto Prince Gustaf Adolph Sea, hopefully to camp over water at least 250 m deep. The new tractors and sleds made the going much easier than in the past. However, unscheduled stops had to be made to repair flat tires. The extreme cold and rough terrain would massage a tube within the brittle tires making it slip inside its tire and shear its valve-stem. Then, in the glow of a kerosene lamp, the track had to be jacked up, the offending wheel removed complete with its grotesquely distorted tire and warmed in a hut. The tube was either replaced or repaired while the coffee perked. Then the wheel was reinstalled while we fervently hoped it would not happen again. Only once again, fortunately. We reached a tentative camp site on a flat frozen lead where a star shot and radio bearing indicated that we should have at least 250 m of water beneath us according to the isobaths on our chart. A sounding was made through a quickly drilled nine-inch hole; the depth was an acceptable 244 m. The lead we were on was 1.8 m thick, a thin barrier to the sea below compared to the old Arctic pack ice covering 95% of the area.

Working by lamp-light, a hydrographic hole was blasted after a ring of holes was drilled almost through the ice. Removal of the debris was followed by setting up an insulated shelter over the hole where Dick would work. It was heated—usually far too much—by the same heater used for preheating the tractors' engines. Dick would work with his shirt off while it was -50°C outside. Hydrophones were lowered to the sea-bottom through holes drilled at three of the corners of a 105-m horizontal square, the idea being to determine the directions from which pulses of under-ice noise originated. Each hole was preserved with an air bag but this time a bag was held down while being inflated by a plywood disc made immovable by a pair of hinged, steel hoops with serrated rims that jammed into the top of the hole.

Our sensors included an anemometer and a string of forty temperature-sensing thermisters. All but the uppermost thermister were frozen in a small vertical hole in the ice. With the hydrophones, these sensors were sampled every 20 minutes for two and a half weeks in February, during which time there was a variety of wind speeds and air temperatures. The only evident biological noise was from the skittering around of an Arctic fox chewing on steak bones.

One hut had the kitchen equipment and fold-down bunks, the other housed the electronics so those on watch did not interfere drastically with sleeping and eating. During this time, we savoured our choice of frozen food. The designated cook for the 'day' would ask

John-G how he would like his steak, knowing what the answer would be. The answer was always, "Fry the ass off it and no vegetables please!"

John Ganton, Dick Herlinveaux and John O'Malia

One day, we got a radio message from MOT saying that an RCAF Viscount, with Trevor Harwood aboard, was in the vicinity and would overfly our camp and to standby on our radio. John O'Malia switched on the rotating flashers on top of the vehicles and soon we spotted the navigation lights of the aircraft far above us in the darkness. Trevor said, "I see your lights. How are things going?" I replied, "We're fine, and all is well. How are you?" He gruffly commented that he was checking up on us!

Toward the end of the month, our work was essentially complete and its future analysis[13, 14, 15] was grabbing our attention. Then Dick, looking pale, complained of stomach cramps. I radioed MOT and requested a medical evacuation flight for Dick in two days' time, during which we expected to pack up and get to Isachsen. We followed the remnants of our vehicle tracks and got to Isachsen in time only to find the weather had closed in and the pilot of the C130 saying, "I cannot see your runway." Fortunately Dick's health got no worse. The C130 sneaked under the overcast on 3 March. Dick got aboard and was attended to by a lovely young nurse, which did much to buoy his morale. (It turned out that he had an intestinal infection brought on by diverticulosis which was cured after hospitalization.)

With Dick winging southward, John-G, John-O and I spent a few days sorting our equipment in preparation for delivery of some of it to Resolute where John-G and I had a rough plan in our minds for a field trip next winter onto the ice of Barrow Strait. We loaded our cargo into the next dead-heading C130 to Resolute, first loading our PNL-bound gear followed by the equipment destined for Resolute. In Resolute, MOT very kindly allowed us to store the tractors and other gear in their South-camp garage. Some of the sled runners had to go south for reinforcing after having been bent by collisions with hard ice. After a few days in Resolute our Northern sojourn for 1964 was over and it was good to get home after two months away.

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[13] A.R. Milne and S.R. Clark, "Resonances in Seismic Noise under Arctic Sea Ice," *Bulletin of the Seismological Society of America*, Vol. 36, No. 8, 1797-1809, (August 1964).

[14] J.H. Ganton and A.R. Milne, "Temperature and Wind-Dependent Ambient Noise under Midwinter Pack Ice," *Journal of the Acoustical Society of America*, Vol. 38, No.3, 406-411, (March, 1965).

[15] A.R. Milne, "A Statistical Description of Noise under Shorefast Sea Ice in Winter," *Journal of the Acoustical Society of America*, Vol. 39, 1174-1182, (1966).

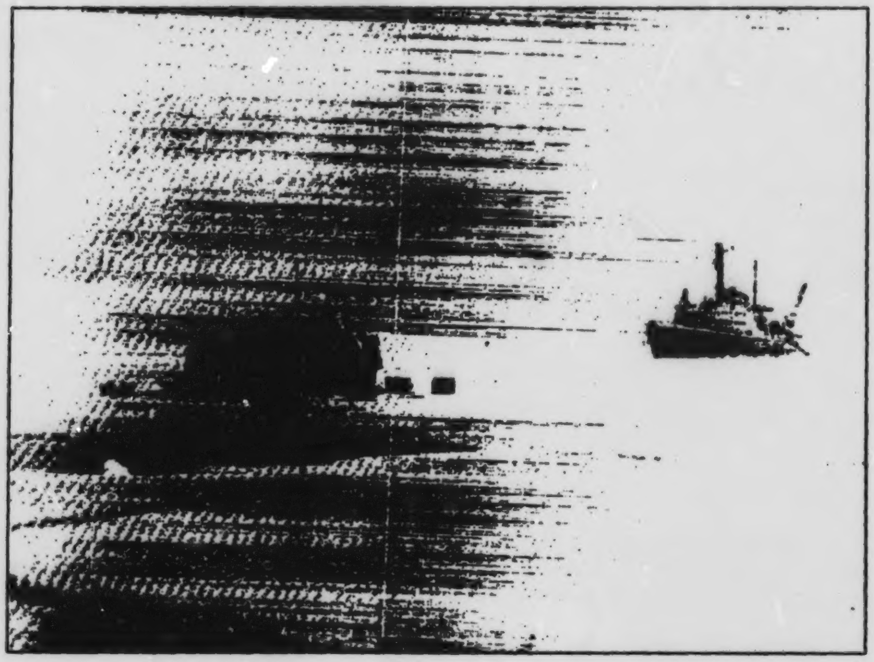
Viscount Melville Sound, September 1964, 'Icepack 6'

Preparations for reverberation measurements under summer ice

The main reason for this field trip, as related by Ray Brown, was to expand on the brief time spent on making reverberation measurements under the sea ice in September, 1963, and if possible to venture westward into the Beaufort Sea, a destination then abandoned as a consequence of heavy ice in the Northwest Passage. Field equipment, essentially identical to that used briefly on *Icepack 4*, with some revisions made by Dave Brown, was delivered to RCAF Namao in early August 1964. Included was a new but similar version of our tent-shelter, the old model having suffered from a flaming misadventure. Explosives were delivered earlier for pickup at Resolute. Arrangements were made through DRB/HQ for temporary accommodations at the RCAF Station, Resolute, for RCAF transportation, and for the use of the icebreaker CCGS JOHN A MACDONALD on completion of its sea-lift escort duties for cargo going to Resolute. In normal years, escort duties were over by mid-August.

With high expectations, the PNL crew, consisting of Ray Brown, Dave Brown, Tom Hughes, and Dave Street, to which was added Pat Crean from the Pacific Oceanographic Group, flew to Namao. Then, in company with their cargo, they embarked on a C130 and landed in Resolute on 10 August.

A disappointing field trip



Icepack 6 **- camp and icebreaker in Byam Martin Channel**

They waited and they waited and they waited! It turned out to be one of the heaviest ice seasons on record, resulting in prolonged icebreaker escort duties. At long last, the JOHN A MACDONALD arrived in Resolute's harbour on 28 August. Our valiant but impatient crew and their field equipment got aboard in record time. The ship then headed westward toward the Beaufort Sea to seek suitable ice over deep water on which to safely perch the scientific party. The ship crunched and bumped its way 200 nautical miles as far as Winter Harbour, Melville Island, where it broke off part of one propeller while going astern through rock-hard polar ice. Then, forced to back-track toward Byam Martin Island, suitable ice for a much limited program was found in Byam Martin Channel, over water 275 m deep. The icecamp was hastily set up between dinner and 11 p.m. Reverberations were recorded[16] and a hydrographic cast made the next day with the icebreaker standing off to minimize acoustic interference. By late evening the word from the captain was that he had to get back to escort duties and would have to leave in the morning. That evening the camp was dismantled and lifted aboard. It was over.

The JOHN A. MACDONALD made it to Resolute on 5 September and by 8 September the PNL crew was on its way to Namao. Apparently the reason why the ice conditions were so bad was a summer with only 992 hr of sunshine compared to a ten-year average of 1358 hr of sunshine. Twenty-nine days away and only one day's field work! Ray exclaimed, "I sure can pick them!"

Not one of the more successful experiments, but it attracted considerable local interest

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[16] J.R. Brown and D.W. Brown, "Reverberation Under Arctic Sea Ice," *Journal of the Acoustical Society of America*, Vol. 40, No. 2, 399-404, (August 1966).

Barrow Strait, January and April, 1965, 'Icepack 7'

Plans for our first remote recording of under-ice noise

The germ of an idea devised by John Ganton and me hatched soon after our return from our *Icepack 5* winter field trip of January and February, 1964. We would install a hydrophone under the winter ice of Barrow Strait in January 1965. The sounds it sensed would be recorded for three months in an instrument package on the ice. The recorder would be simple, designed to select frequencies of sound in the main bandwidth emitted by ice cracking noise. A small battery-powered paper-chart recorder would sample the noise, its intensity to be related to the normal weather parameters observed at the MOT weather station at nearby Resolute. At the same time we would test several methods for preserving holes drilled in the ice in anticipation of future needs for long-term hydrophone installations.

The hole preserver devised by John, that we were 100% certain would work, consisted of a length of plastic pipe, its outside solidly wrapped with one-inch nylon rope and permeated with a soft, jelly-like filler. The hydrophone cable would be inserted through the plastic pipe installed in a hole in the ice and allowed to freeze in place. Recovery of the pipe, with its cylinder of internal ice containing the cable, would be achieved by grasping the loose end of the rope and unpeeling it from the pipe to leave it free to lift out. Scheme number two was to simply inflate a rubberized bag in a hole and hope it would not leak air. Similarly, scheme number three was to use an air-bag and to ensure its inflation with a SCUBA tank and regulator in the water under the air-bag.

Our plan was to use one of our Logan tractors for carrying field gear and fuel and to pull a cargo sled loaded with one of our Caveman huts. To get this organized, Bill Burroughs and I travelled to Resolute in August 1964, to install our re-engineered sled runners and to reconfigure our tractor train. We took with us a bundle of bamboo poles and other required equipment—the electronics would come later, in January 1965. As usual, we bunked in at the RCAF station and were ably assisted by MOT staff and their vehicles.

The installation team, in January, would be John Ganton, John O'Malia and myself. The instrument recovery team, in April, would be

Al Milne inserting a hydrophone through the ice

John Ganton, George Beath and John O'Malia. (In April, I would be leading *Polarpack 2* on the Arctic Ocean out of Mould Bay.)

Instrument package installation and recovery

The installation of the remote recorder in January entailed searching for a route to Barrow Strait from Resolute's harbour to a site over reasonably deep water in total darkness except for the glow of our tractor's headlights. Before we left, we visited the Eskimo village and called on Idlout, one of the best hunters, to get his opinion on a route to take onto the ice. We were invited in to tea served by his wife, with his son acting as interpreter. After praising the tea, we were told that it was so good because it was made from melted ice from an iceberg. Heeding Idlout's advice, we set out onto the ice, installing bamboo poles with black flags on top along the way, setting them into holes augered by hand. These were to serve mainly as markers to be followed by the recovery party in April. Hopefully, the poles would not be attacked by bears, which turned out to be the case.

It was a three-day effort that went off without a hitch. The sensitive hydrophone and its preamplifier, at the end of its cable, was threaded through the plastic tube 'hole-saver' and then through a nine-inch hole drilled in the two metre thick winter ice. The rope-covered plastic tube was then inserted and suspended in the hole with a tag end of the recovery rope anchored on the surface of the ice. After the recorder was tested, and the two dummy hole-savers were inflated, we retraced our route by following the bamboo poles back to Resolute.

The tractor and sled were stowed back into the MOT garage along with equipment to be used by the recovery party in April. We caught the next regular 'Herc' to Namao feeling very smug about the remote recorder's successful installation and hoping that months of data would help to firm up the relationship of air temperature to ice tension-cracking noise.

John Ganton, George Beath and John O'Malia headed to Resolute in mid-April on a C130 from Namao. After extracting the tractor train from the MOT garage, they had no trouble following the line of bamboo poles to the remote recorder, hoping on the way that a curious bear would not have tested the palatability of the recorder or decided to pull out the rope from around the plastic hole-saver. All was well; the recorder was still slavishly fulfilling its destiny. A quick look around at the two inflatable hole-savers showed that they were dismal failures and deserved to be unceremoniously abandoned. Then John O'Malia tugged on the rope wrapped around the plastic pipe hole-saver and it unravelled from its jelly-like matrix as it was designed to do—how gratifying! After the ice-filled pipe was heaved out of its hole, and as the hydrophone cable was being hauled up, an axe was wielded to completely free the cable. Chalk one up for a good idea![17]

The results, though minimal, opened exciting possibilities for future under-ice recording instrumentation.[18]

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[17] J. Ganton, "Arctic Field Equipment," *Journal of the Arctic Institute of North America*, Vol. 21, No. 2, 92-97, (June 1968).

[18] J.H. Ganton, "Remote Noise Recorder," *Journal of the Acoustical Society of America*, Vol. 16, No. 2, 271-277, (April, 1966).

Arctic Ocean, April 1965, 'Polarpack 2'

A quickly conceived plan for an icecamp out of Mould Bay

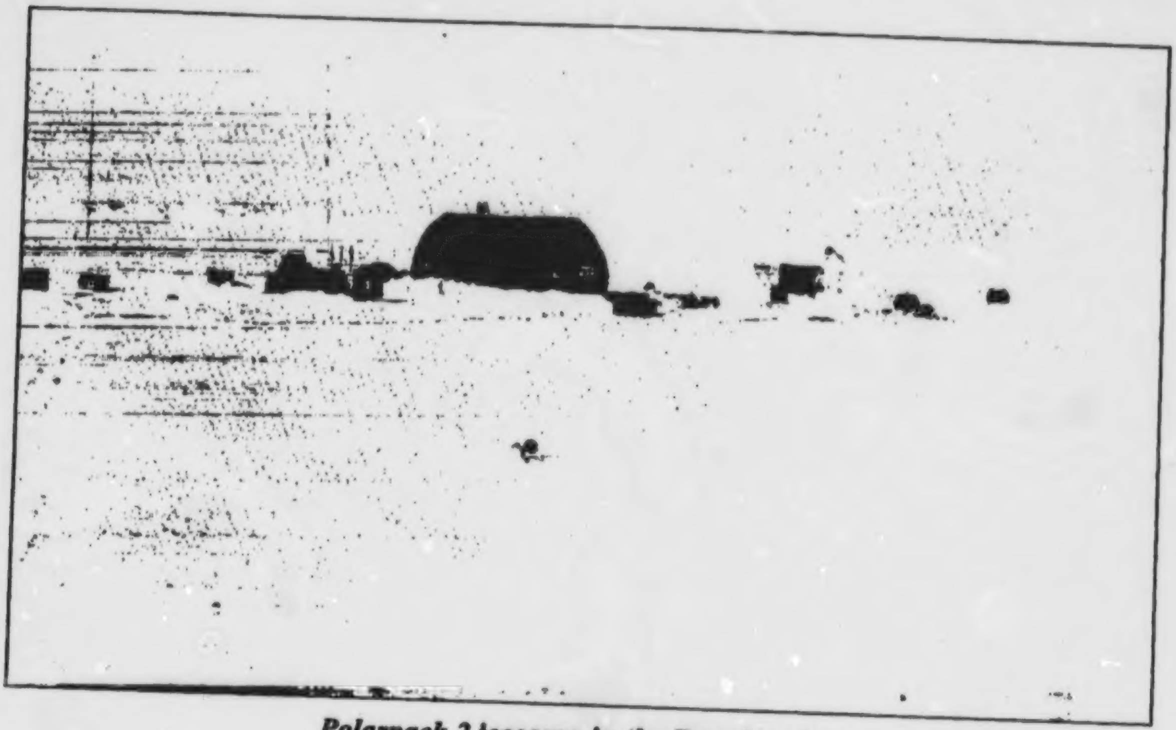
After my brief winter trip out of Resolute in January on *Icepack 7*, Fred Roots phoned me offering to support us in a field trip out of Mould Bay, Prince Patrick Island, during the spring of 1965. This was a short couple of months in the future, but an offer not lightly to be rejected. I quickly scurried around PNL to drum up the interest of those Arctic hands not already committed to a spring operation. Ray Brown became keen on the idea, having in mind a chance to get reverberation measurements done in the deep water of the Arctic Ocean. He had been doubly frustrated by the failure to get there on icebreakers in the summers of 1963 and 1964 on operations *Icepack 4* and *Icepack 6*. Oceanographer Pat Crean, from the Pacific Oceanographic Group, jumped at the chance to join our crew, as did Ray (Sam) Hale of PNL. Sam would provide the comforting ham radio and other electronic skills. Our cobbled-together under-ice program would consist of reverberation, ambient noise, and explosive sound propagation measurements. These would be interspersed with hydrographic casts. Fortunately, all the required field gear existed and we only needed to order explosives and field rations and arrange for RCAF flights to Mould Bay, targeting a date in late March. Fred Roots would look after the rest. Tom Hughes, with his usual diligence, supervised the listing and packing.

A comprehensive medical kit was part of our field equipment. It included prescription items, designated by a trauma surgeon at the Victoria Jubilee Hospital, such as sutures, injectable painkillers, catheters, antibiotics, and splints and bandages. After the episode with Dick Herlinveaux's illness on *Icepack 5* and, earlier, Carl Kelly's axe injury on *Icepack 1*, it was evident that a mere first aid kit would not do. We were fortunate to be given a series of lectures and demonstrations by physicians at the Victoria Jubilee Hospital, including hands-on stitching up of cadavers. The latter caused several fainting spells amongst our 'cool' Arctic scientists!

A very pleasant and productive field trip

In late March, we met our field gear in Namao, it having arrived by PNL's truck the previous day. Some six hours later, our C130 sat down in a semi-white-out in Mould Bay. After conferring with Frank Hunt, Polar Shelf's field supervisor, we were assigned two 'Single' Otter flights to establish a camp on a frozen lead 290 km WNW of Mould Bay over water 2476 m deep. The Otter pilots were experienced in selecting safe ice to land on so we were not unduly concerned about getting wet. Both aircraft were equipped with Decca-Lamda positioning receivers. These, together with our own LF beacon, assured us of being located again despite the drift of ocean ice in the Gyre.

During the month we were camped on a long smooth lead, the weather was generally calm and air temperatures were in the relatively pleasant -15°C to -30°C range. Ambient noise and reverberation recordings were made and Pat Crean made several deep hydrographic casts. It was noticeable that Pat was a voracious trencherman. When I commented on his joy for food, he told us of his experience during the war of being brought up in an orphanage in which he was brain-washed into a permanent yearning for food!



Polarpack 2 icecamp in the Beaufort Sea

Ray Brown and I used a Bell 204B turbine-powered helicopter as a shooting vehicle to a range of 80 km to the WNW of our camp. This took five days' work, during which the pilot and his mechanic ate with us and slept with us on our shelter floor. We had solved the radio link problem that had plagued us on *Polarpack 1* by setting up a dipole antenna each time we had a shot ready to detonate. During this time, several Otter flights delivered turbine fuel for the helicopter, which slurped up fuel very greedily. Unfortunately, we had to abandon a cache of eight valuable drums when we finished our work, the result of an unsolicited delivery. I could imagine them drifting around the Gyre to be ejected eventually into the North Atlantic for a Newfoundland sealer to salvage.

Pat Crean and Ray Hale making deep hydrographic casts

We were home by early May and set to work on data analysis,[19],[20] only to be tempted by another offer of field support in the Arctic Ocean, this time using a US Navy icebreaker.

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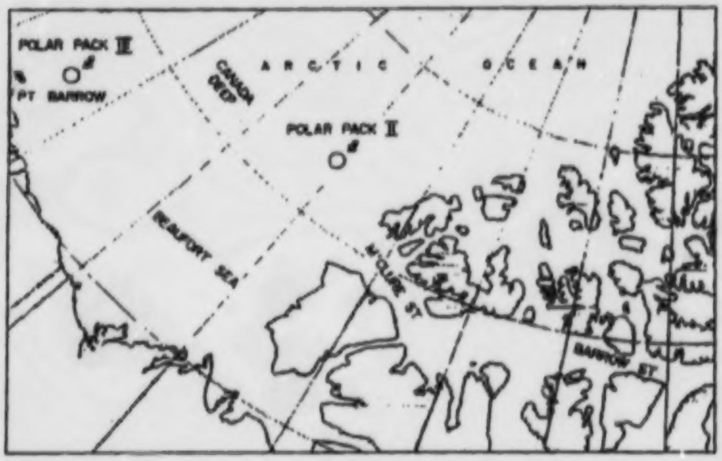
[19] J.R. Brown and A.R. Milne, "Reverberation under Arctic Sea-Ice," *The Journal of the Acoustical Society of America*, Vol. 42, No. 1, 78-82, (July 1967).

[20] A.R. Milne, J.H. Ganton, and D.J. McMillan, "Ambient Noise under Sea Ice and Further Measurements of Wind and Temperature Dependence," *Journal of the Acoustical Society of America*, Vol. 41, No. 2, 525-528, (February 1967). Note: This publication also contains an analysis of ambient noise recorded during *Polarpack 3* (1965) and *Icepack 4/66* (1966).

Beaufort Sea, August 1965, 'Polarpack 3'

Another 'instant' scientific plan for 1965



Locations of *Polarpack 2* and *3*

I no sooner got settled in at home and office than I got a phone call from Dr Alan Beale at the USN Underwater Sound Laboratory in New London, Connecticut, offering me the use of the USS STATEN ISLAND in the Beaufort Sea that summer. He said that he was designated chief scientist but had virtually no viable experimental program for the summer, being saddled with an unserviceable low-frequency projector he had intended to use in the Beaufort Sea. The vessel was going to be off the North Slope in any event during August and available for us to use. The STATEN ISLAND was based in Seattle and could dock in Esquimalt Harbour on 8 July to load PNL's gear. Our crew could then meet the vessel off the Arctic Research Laboratory at Point Barrow, Alaska, at the end of July.

After a quick consultation with a prospective Arctic field crew and PNL's hierarchy, I called him back saying that we'd be ready with our gear and would have a program available. Alan was pleased and said that I would be the *de facto* chief scientist. Our program would be essentially the same as on *Polarpack 2* except that we would use 16-lb Nitrone charges for our sound transmission work when using the icebreaker as a 'shooting' platform. Then underwater sounds would be loud enough to generate not only signals through the water but also sub-ocean bottom seismic signals[21] well above the ambient noise. PNL's crew was Bill Burroughs, John O'Malia, Tom Hughes and myself. Pat Crean, from the Pacific Oceanographic Group, was to be our oceanographer. Three researchers from the Naval Electronics Laboratory (NEL) in San Diego would also be aboard. They would be extracting ice cores for future analysis and would also record seismic reflections from within the sea bottom using surface explosions.

The USS STATEN ISLAND, a chunky, grey, WIND class icebreaker, arrived in the Esquimalt Dockyard, as expected, on July 8. I made myself known to the ship's executive officer, LCdr Isadoro Maggay, who then directed the loading of our field equipment below decks. Ted Fleischer installed a hydrographic winch for Pat to use.

My wife, Laura, and I had a plan to entertain the ship's officers the next day and had a number of PNL's scientists and their wives invited and lined up with salads, casseroles and wine. My invitation was accepted with the caution that there would be about thirty-five officers plus the captain and his wife attending—an unexpected inundation! After a flurry of phone calls, more dishes, cutlery and chairs were promised. Then the captain, Cdr Donald Bonewits, and his wife arrived by staff car an hour early, but all was ready. He apologised, having been misinformed of the time by the executive officer. It turned out to be a good opportunity to get to know them before the other guests arrived. Promptly at 1800 hr, a huge Dockyard bus came down our narrow, winding driveway and delivered the ship's officers to the waiting preparations. The evening was a roaring success, the Officer boisterousness being moderated somewhat by the Captain's presence!

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[21] A.R. Milne, "A Seismic Refraction Measurement in the Beaufort Sea," *Bulletin of the Seismological Society of America*, Vol. 56, 775-779, (June, 1966).

To our camp on the Beaufort Sea

The five of us—John, Bill, Tom, Pat and I—left Victoria Airport on 25 July by Alaskan Airlines to Fairbanks. The next day we arrived in Barrow on Wien Alaskan Airlines and stayed overnight at the Arctic Research Laboratory (ARL). The USS STATEN ISLAND was anchored well offshore in open water and soon their Sikorsky 'horse' arrived to pick us up. After we had donned immersion suits and clambered aboard, the helicopter 'clopped' its way low over the water to the icebreaker, where we were welcomed and shown to our quarters. We were berthed in an open area between decks lined with a forest of posts between which hammocks were rigged. I had to be instructed on how to get into and stay in a hammock. Hardly the class of sleeping quarters we were used to in Canadian icebreakers!

Evidently word had been passed to LCdr Maggay that I was the chief scientist so he expected me to provide a written plan of action each day by 0800 hr. I requested that the vessel proceed in a NW direction with the aim of reaching a location beyond the Continental Shelf and over abyssal depths where PNL would set up an icecamp. From that location, we would use the icebreaker as a shooting vessel for our under-ice sound transmission work and to independently measure reverberations. On the way to the icecamp location, the helicopter would be used to land away from the ship to record under-ice ambient noise.

John O'Malla, Tom Hughes and Bill Burroughs drilling through an icefloe

As we headed to the northwest, open water diminished, the ice becoming a less tractable 10/10ths with an increasing concentration of multi-year floes. At one point the ship attempted to break a multi-year floe to access a long open lead. The floe was eventually breached after a passage was blasted through the floe. Occasional stops were made along our tortuous route for Pat Crean to make hydrographic casts and for the NEL people to fire off 400-lb charges on the ice in order to record sub-bottom reflections and to take ice cores. Once, while John was assisting an NEL ice party to use our drill motor to power their ice-corer, a polar bear was seen stalking them by the ship's lookout. The bear was distracted from its prey by vigorous yelling from the foredeck crew while the ice party showed their sprinting prowess! During the days that followed, I often dined with the skipper who on one occasion confided that he had spent all his sea-going life learning not to hit anything and it took some time getting used to ramming ice floes.

On August 10, the icebreaker attempted to break through a neck in a large floe. After several rammings no progress was made. Then as it reversed again, diesel oil was seen oozing into the water off the bow and forming an orange-hued rim of oil on the floe. This caused some consternation on the bridge, at which point a diver was lowered over the side to view the damage. Upon surfacing, the diver bellowed, "This ice is deeper than the keel!" It was over ten meters thick and the ship had tried to split a huge paleocrystic ice floe. Fortunately, the one and a half metre gash in the hull had breached only a small bow tank and the damage was not serious. At that location the water depth was 3,700 m, so I decided—and the skipper agreed—that we would use that floe as a platform for our camp. The skipper also decided that the large flat floe would provide a safe place for the crew to get off the ship and have a 'tea party' and sports day. A hole was drilled and a mooring post installed, then a ladder was slung over the side, whereupon all the ship's personnel except the watch disembarked, complete with appropriate beverages, snacks and Ahkio sleds to be used in races.

After the festivities were over—hastened by the Arctic chill—our camp equipment was winched onto the ice and moved by sleds to an adjoining floe with ice only 3 m thick to make it possible to get access to the ocean. The ship provided groceries and insisted that we erect

STATEN ISLAND and ***Polarpack 3*** **icecamp**

their radar reflectors, being suspicious of the effectiveness of our LF beacon for relocating our camp. Tom and I manned the camp while Bill and John took on the job of detonating our underwater charges from the stern of the STATEN ISLAND. John had set out a dipole antenna around the edge of the safety net on the helicopter deck, and once under way, rigged charges off the stern under the helicopter deck. Communication with the bridge was by ship's telephone. Once systems were tested, the ship meandered through narrow leads in a generally southeast direction, setting off underwater charges to a distance of 60 km from our camp. Bill and John had an exacting task, making sure that each charge was fully immersed to 90 m, and not hung up on the back-wash of broken ice, before setting them off. All went well with no complaints about the slamming of the explosions under the vessel's stern.

The icebreaker made good time, getting back to our camp after an absence of eight days, following which our camp was hastily disassembled and stowed aboard. Cdr Bonewits was somewhat anxious to get back to Barrow to get some emergency repairs done to the bow. Our work was complete and with good conscience we could enjoy the evening movies and the bushels of popcorn, some of which spilled on the floor making it look like the aftermath of a hail storm. By August 20, we were off Point Barrow and were put onto the beach using a small landing craft. We were on our way home.

Al Milne recording sounds from underwater explosives set off from the USS STATEN ISLAND

M'Clure Strait, April 1966, 'Icepack 4/66'

Plans to test stability of under-ice acoustics in the springtime

While I was off in the Arctic Ocean on the USS STATEN ISLAND in the summer of 1965, John Ganton had been devising a means for testing a feature of under-ice acoustics that we had speculated might be of use in the detection of submarines. For the winter and spring, when the ice cover in the channels between the Queen Elizabeth Islands is virtually motionless, echo-ranging from a fixed position should more easily detect a moving submarine, assuming that repetitive echoes from the ice could by subtraction cancel each other. (This underwater environment is completely different from that under sea waves where target motion would be more easily obscured by dissimilar background echoes from moving waves.) All we needed to do was to transmit sound-pulses from a sound projector on the sea bottom at an icecamp. The resulting reverberation from the ice cover would be detected by a hydrophone rigidly attached under the ice near the camp. Then we would examine the coherence, or similarity, between the successive reverberations picked up by the hydrophone.

To do the job, two projectors were ordered, one tuned to project pulses in the 3-4 kHz range and the other tuned to project pulses at frequencies below 1.2 kHz. Several small 'dollar watch' hydrophones were obtained, one to be mounted on a pole 1 m under the ice at the icecamp. Otherwise the required equipment was at hand at PNL, the USS STATEN ISLAND having delivered to Esquimalt Harbour our field equipment used on *Polarpack 3* in the summer of 1965. We also planned to record under-ice ambient noise and chose M'Clure Strait as a destination for the spring of 1966 since we had no under-ice noise data for that significant strait. Our crew would comprise John Ganton, Tom Hughes, Pat Crean, from the Pacific Oceanographic Group, and myself. Fred Roots would provide us with 'Single' Otter flights and radio backup out of the Polar Shelf Base in Mould Bay, Prince Patrick Island. The RCAF agreed to fly us and our gear in a C130 Hercules from Namao, Alberta, to Mould Bay and we could return to Namao using a dead-heading re-supply 'Herc' on completion of our field operation.

A cracked projector revises expectations

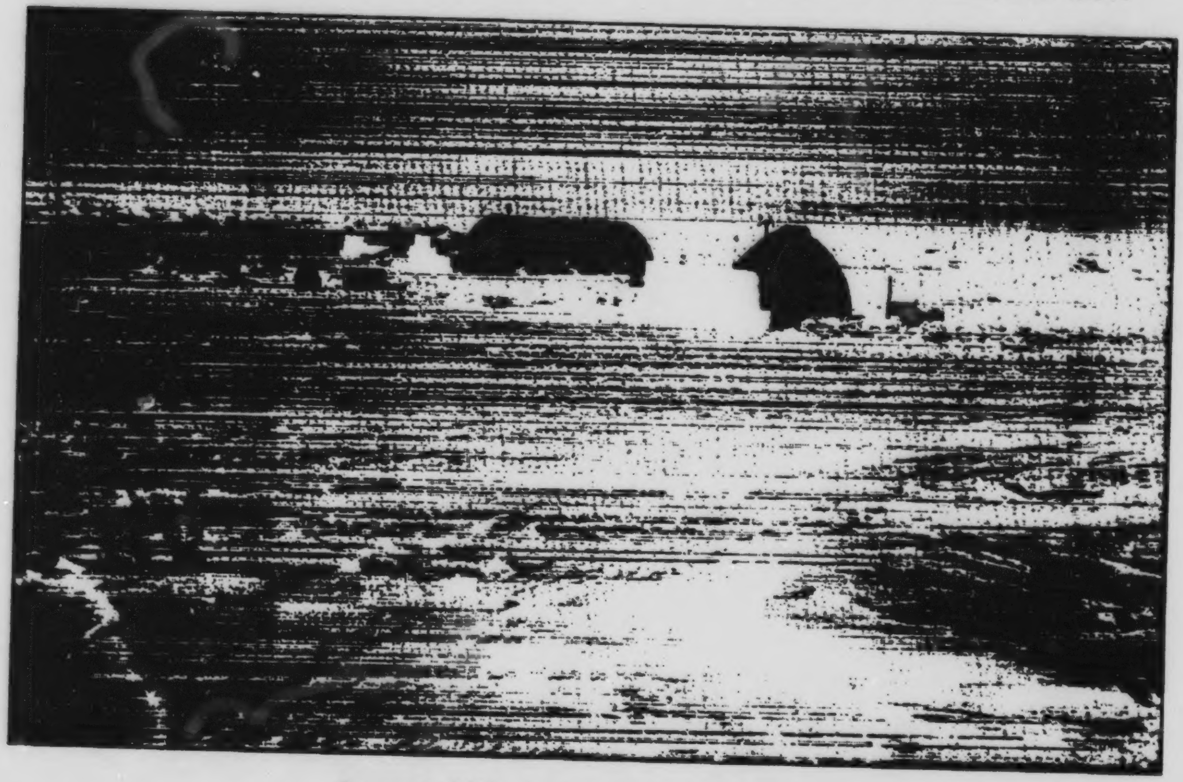
We were on our way to Mould Bay by mid-April where we sorted our cargo to ensure that our first Otter flight would contain all the camp equipment necessary for our survival. We landed on a lead of one-year ice in a jumbled field of two-year ice about half-way between Melville and Banks Islands. The weather was clear and while we assembled our camp, three more Otter flights homed in on our beacon to deliver the balance of our 5,000 lb of equipment. Our venerable insulated tent-shelter housed our electronics while a short version, complete with a stove and kerosene lamp, was erected over the hydrographic hole, ensuring that Pat would work in unaccustomed comfort.

After lowering the larger of the two sound projectors 451 m to the bottom, it became disappointingly clear that it had lost most of its muscle in transit, making us revise the stability part of our program. Instead of recording reverberation, we decided to record directly transmitted sound pulses sensed by two hydrophones rigidly mounted on poles under the ice 400 m and 800 m distant from the camp. The almost unvarying time difference between pulse transmissions and their detection provided a measure of the stability of the void beneath us. The slow tidal rise and fall was evident throughout the long series of recordings on twenty ten-inch tape reels.[22]

Before dinner one evening we relaxed by having a joint song-fest, singing into a microphone attached to the projector's amplifier. Irish ditties, lustily sung by Pat Crean and picked up by the distant hydrophone, became sepulchral and we speculated on their effect on the resident seals.

To record the ambient noise, our sensitive hydrophone was lowered to the sea bottom. Numerous samples were recorded, along with wind speeds and air temperatures. Results showed the expected wind and air temperature dependence. During times of very low ambient noise, the hydrophone picked up the gabble and grunts of distant seals. The occasional rasping sounds of seals enlarging their breathing holes were heard. The strangest sounds occurred mostly in late afternoon. These were five-second-long whistling tones of decreasing frequency that we attributed to ascending deep-diving seals. These have since been anecdotally attributed to bearded seals. We never did detect any other evidence of seals in our local area.

By mid-May our work was complete and on our scheduled radio call to Polar Shelf radio at Mould Bay I arranged for our camp to be picked up. Four Otter flights later and after a few days in Mould Bay our 'Herc' arrived via Resolute and we were on our way home. Delightful though this prospect was, John and I were somewhat anxious to know if our proposal to construct 'Recording Instrument Packages' had been approved, time being short for making arrangements for an icebreaker to lower them into Arctic channels in the summer of 1967.



***Icepack 4/66* camp in Lancaster Sound**

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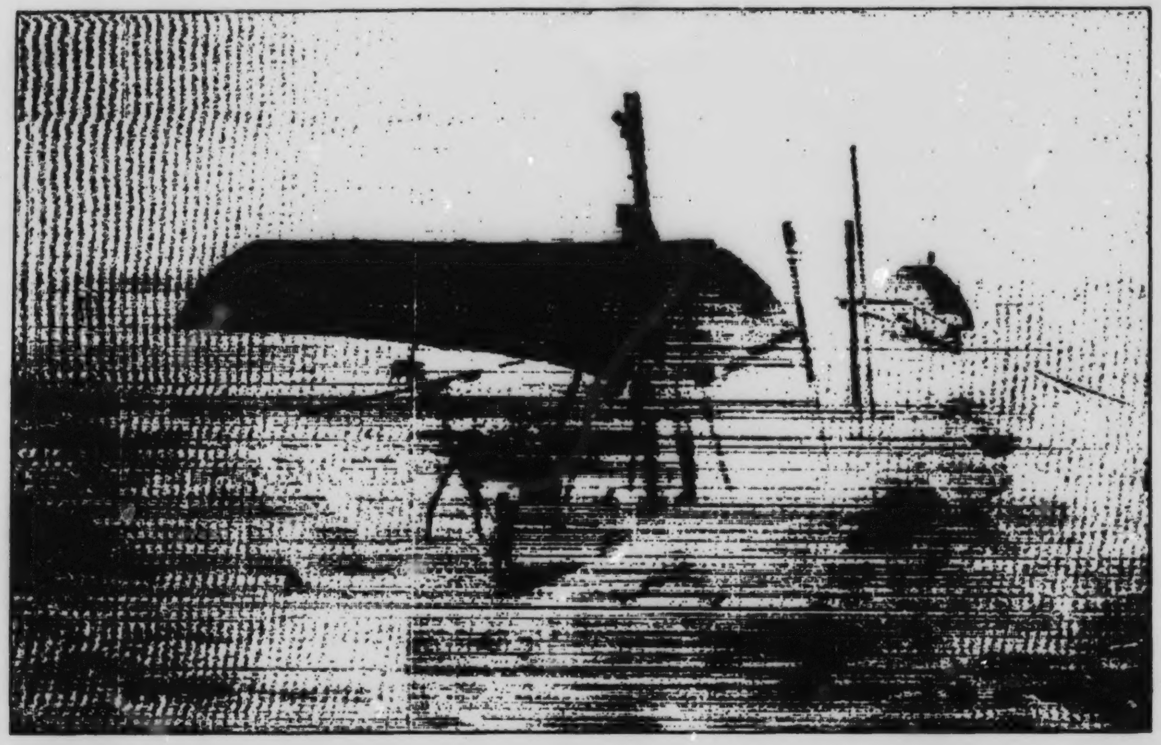
[22] A.R.Milne, "Under-Ice Acoustic Stability: Preliminary Experiment and Theory of Measurement," *Defence Research Establishment Pacific Report 68-1* (January 1968).



After storm in Lancaster Sound

Coffee time: Tom Hughes, Al Milne and Pat Crean

Installing RIPs, August/September 1967, 'Icepack 8/67'

A short fifteen months to design, construct, and test RIPs

In our absence, it was clear that John and I had relied too much on the power of the written word and quickly arranged for a meeting with Dr Fred Sanders, our Superintendent at the time. We had given much thought to the catchy acronym 'RIP' to call our recording instrument package and intended to test its impact. After giving our scientific and technical briefing, we said we proposed to name each of the five units 'RIP' to symbolize their long-term passive characteristics. After a brief pause, Fred broke out in a grin. We knew we had approval!

The intent of the RIP was to record, unattended, the natural noises in the Arctic seas of the Canadian Archipelago for a year. Five were to be built and tested in the short fifteen months available before we hoped to lower them to various sea-bottom locations from an icebreaker in September 1967 for recovery a year later. The heart of the RIP consisted of a battery-powered state-of-the-art system to sample and record ten different parts of the ambient noise spectrum each hour. A sensitive hydrophone, uppermost on each RIP, would translate the loudest as well as the most diminutive sounds into electrical signals to be sampled. We expected to obtain ambient noise data to fill in gaps in those times of year when it is most difficult or virtually impossible to launch manned field operations. As well, we could drop a RIP anywhere, within its depth limitations, that an icebreaker could access.[23]

Our original conception of a RIP was mostly as an aesthetically neat, buoyant sphere weighted by a battery-pack. This evolved by necessity into a clumsy but functional platform upon which was mounted all the RIP's component parts and having an all-up weight of 2,100 lb in air and 1,100 lb in sea water. One essential feature was to be able to lower a RIP under control, but have it disconnect from its tether. This was achieved by using a 'foot' beneath the RIP, which when it sensed the bottom, removed the 'safety' on the cable disconnect mechanism, which in turn, would release the RIP when the load on the cable slacked off. Another essential feature was the recovery system. A steel rope attached to a RIP was wound on a drum and attached, in turn, to a light polypropylene line and a float, the latter restrained by an explosive bolt. If the hydrophone heard a specially coded sound sent by a sound projector from an icebreaker, the explosive bolt would fracture releasing the float dragging its light line. Nearing the surface, which could be covered with ice previously broken up by the icebreaker, a small container within the float would eject a brilliant green dye. A second container would flood to activate a sea water battery, the power source for a homing radio. These devices proved their worth during RIP retrievals in 1968. Once the float was snagged, the light line would then be used to unreel the steel rope used to lift the heavy RIP.

While most of the engineering and electronics groups at PNL were engaged in RIP design, manufacturing and testing, I obtained, through DRB/HQ, a commitment from the Department of Transport to provide us with a month's icebreaker time, beginning from Resolute, after the summer's Arctic sea-lift escort duties were finished. We would again have the good fortune to use CCGS LABRADOR with our friendly Captain Tooke in command. Also, arranged through DRB/HQ, was an RCAF C130 Hercules to fly us and the five RIPs to Resolute on August 10. Once all that was decided, Ted Fleischer despatched a hydrographic winch and a sturdier winch (to lower the RIPs) to Halifax to install on the icebreaker before it headed north. Scientific personnel—all avid volunteers—were John Ganton, Bill Burroughs, Dick Herlinveaux and myself.

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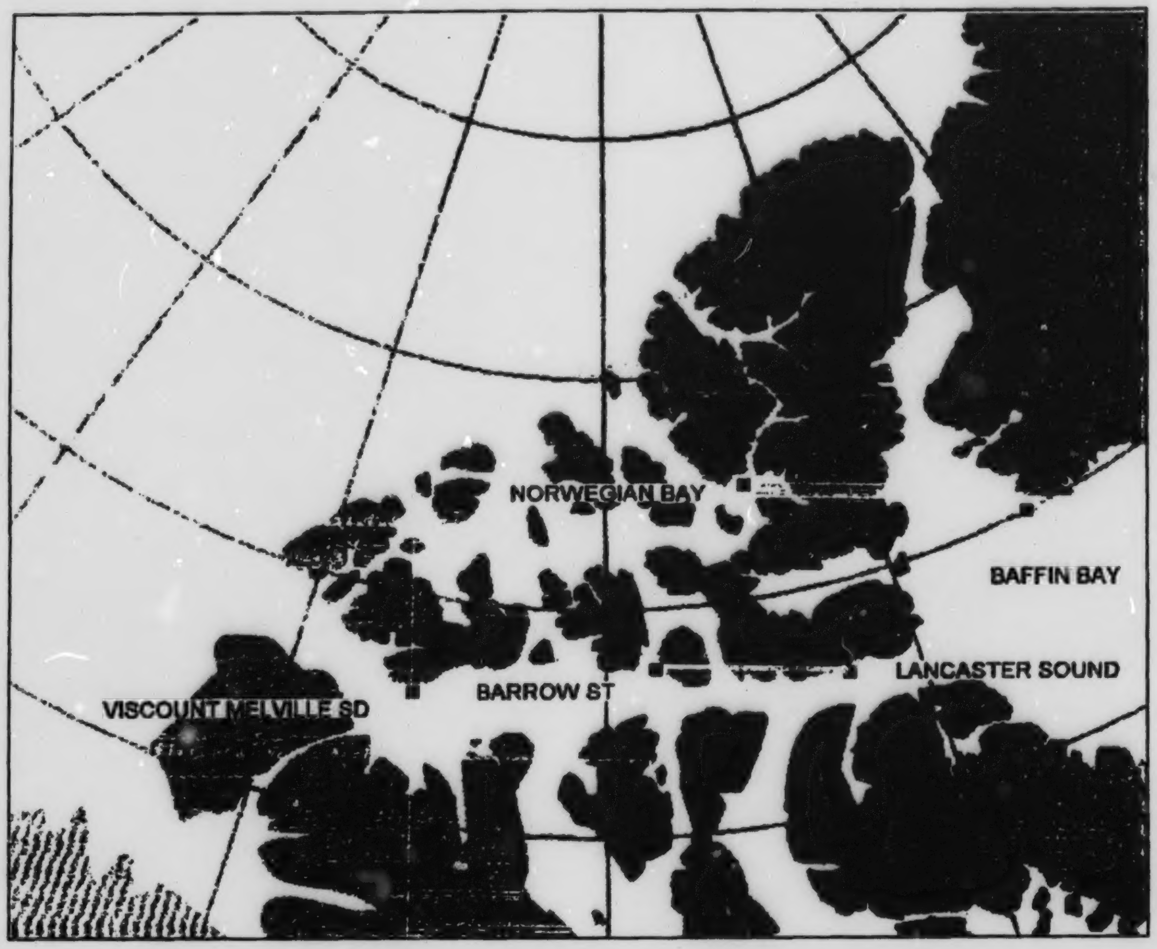
[23] J.H. Ganton, G.N. Dennison, W.H.M. Burroughs and A.R. Milne, "Recording Instrument Package (RIP) for Long-Term Underwater Measurements in the Arctic," *Defence Research Establishment Pacific Report 70-4*, (September 1970).

Installation journeys on CCGS LABRADOR



RIP Sites

RIPs and all got aboard CCGS LABRADOR on 15 August, earlier than expected since 1967 was a relatively light ice year for escort duties. There were limitations on where we could drop our RIPs. Their design depth was a maximum of 2,000 ft and a relatively hard bottom was needed for the release foot to work. The ship's radar was our only means of relocating a RIP site either by re-identifying prominent headlands or by using our radar transponders, or both. The site should not be inaccessible because of heavy polar ice in a subsequent summer. Our plan was to install three RIPs in the Northwest Passage: one in Lancaster Sound, one in Barrow Strait, and another in Viscount Melville Sound. We would also attempt to place a RIP in Norwegian Bay, near the mouth of Eureka Sound, between Axel Heiberg and Ellesmere Islands. The remaining unit we designated for the north end of Baffin Bay, not far off the west coast of Greenland.

Installation Journey - Dick Herlinveaux coring the bottom of Lancaster Sound

Our initial route took us eastward through Lancaster Sound to a site proposed for RIP #1, 500 m deep and 32 km south of Devon Island. There, a bottom core taken by Dick Herlinveaux confirmed that the bottom sediments were stiff enough. Next, John Ganton and I took the helicopter onto nearby Devon Island which, although having a strong radar echo from its precipitous cliffs, has a coast with few definitive features thus making it necessary to use the radar transponders. There we built a cairn and temporarily activated one of the our bread-loaf-sized radar transponders. Twenty km further east on the brow of the coastal cliff, we did the same with our second transponder. The transponders' electronic echoes from known cairn locations ensured that we could relocate the icebreaker over the RIP the following summer. Once RIP #1 was perched on the sea bottom, the ship's radar display was photographed, the transponders were recovered, and CCGS LABRADOR headed off in open water, weaving between bergy bits, toward northern Baffin Bay.

Throughout the voyage Dick Herlinveaux kept busy bottom coring, taking 'bottle' stations, preserving plankton specimens, and being the indispensable winch operator when RIPs were being lowered to the bottom.

Captain Tooke kept LABRADOR near the Greenland side of Baffin Bay to avoid the nearly 10/10ths ice toward the west resulting from the coriolis effect on the southerly surface currents. On 19 August, we chose a site for RIP #2, installing it on a sea-bottom rise, in water 425 m deep, 25 km off Kap Parry, where prominent cliffs with strong radar echoes made deploying our transponders unnecessary. We took note of the numerous large icebergs which calve from Greenland glaciers.

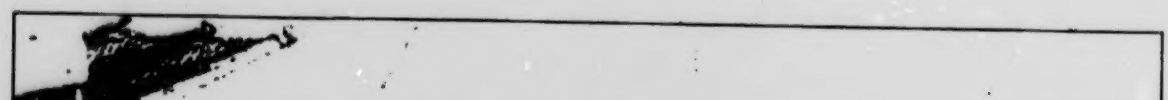
Our next destination was Norwegian Bay, westward through the continuous rotten first-year ice of Jones Sound, northward in the fast-moving floes of Hells Gate and passing low-lying Graham Island to the west. Entering Norwegian Bay, we disturbed a bloody-jawed polar bear engaged in devouring a hapless seal. In 10/10ths first-year ice, a site for dumping

Installation Journey - Radar transponder on Devon Island

RIP #3 was chosen in 200 m depth in the middle of the Bay, 24 km north of featureless Graham Island. Our two transponders were sited on the Island where cairns were made of plentiful shaley rock. RIP #3 was put to rest on 23 August. Captain Tooke was about to head south when he was asked by Ottawa to continue north through Eureka Sound and stand-to off the Eureka weather station to provide helicopter assistance to a joint National Geographic-US Wildlife Service muskox relocation project. Their chartered helicopter had broken down just at the end of their muskox round-up. Our RIP crew appreciated spending a few days ashore as guests at the weather station and helping out with the muskox herding and observing the exciting action from the ship's helicopter. The animals sought after were the yearling calves which were being penned awaiting transport to Alaska.

Viscount Melville Sound was our next destination. The fall freeze-up was beginning with fields of pancake ice forming as we entered the open water of Lancaster Sound. Further west there was complete ice cover and LABRADOR was diverted to assist a late-season ice-strengthened tanker which was beset on its way to the Panarctic base at Rae Point on the southeast side of Melville Island. Fortunately this was on the way to our proposed RIP site south of Winter Harbour, Melville Island. The more or less linear shoreline provided uncertain radar echoes making it essential to deploy our transponders. On 5 September, RIP #4 was lowered to its resting place on the bottom at a depth of 305 m, 32 km off the coast of Melville Island.

Finally, in Barrow Strait on 8 September, our remaining RIP, #5, was successfully perched at a depth of 230 m in a location about equidistant from Bathurst, Cornwallis, and Lowther Islands. Strong, well-defined radar echoes made installing our transponders unnecessary. We were close to Resolute and after thanking Captain Tooke for his exemplary support and making our work easy, we said our good-byes and caught the next RCAF 'Herc' to Namao, ending the year's field work.



Last check by Bill Burroughs on a RIP being launched in an Arctic channel

Viscount Melville Sound, April 1968, 'Icepack 4/68'

Renewed testing of the stability of acoustics under landfast sea ice in the springtime: 'getting it right'

After our tantalizing but indefinite experiment to test the under-ice acoustic environment for its long-term stability in April 1966 *(Icepack 4/66)*, John Ganton had ordered another, but more powerful, sound projector to replace the one that failed that spring. John, Tom Hughes and I planned to establish a camp at roughly the same location at the same time of year in 1968 and were able to lean again on Polar Shelf and the RCAF for logistic support. The main difference in instrumentation was that we mounted two expendable remote hydrophones under the ice, about one and two km from our new sound source, on rigid poles frozen into the ice. The sounds that they received, when short pulses of sound were emitted from the projector, were converted to electrical signals and radioed to our camp using battery-powered telemetry and recorded on magnetic tape. These sounds were a combination of pulses of sound from the projector that travelled in the water both directly and by paths that reflected on the seabottom and under the ice. Pulses were projected for hours at a time, the signals recorded being remarkably similar, changing only slightly as the tide ebbed and flowed. We were justified in thinking that a motion detecting sonar should work well under landfast ice.

Our electronics were well behaved; we were not bothered by polar bears or foxes; we heard the expected 'whistlers' from ascending bearded seals; the weather was consistently good; and we 'got it right' this time.[24]

Icepack 4/68 **- A more powerful projector**

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[24] J.H. Ganton, A.R. Milne and K.B. Ashcroft, "Further Measurements of Stability in Reverberations Under Sea Ice," *Defence Research Establishment Pacific Technical Memorandum 71-5*, (November 1971).

Recovering RIPs [25,26,27] August/September 1968, 'Icepack 8/68'

Arranging a contract to use the deep submersible Pisces 1

What if some or all of the complicated recovery systems on the RIPs failed after a year's immersion? This was the nagging question that spurred my quest to arrange for *Pisces 1* to be aboard the recovery icebreaker in the summer of 1968. (*Pisces 1*, a manned mini-submarine, was currently in use on the West Coast for research projects and by the US and Canadian Navies to aid in retrieving malfunctioning test torpedoes in Nanoose Bay off Vancouver Island.) I telephoned International Hydrodynamics Ltd (IHL) in Vancouver, the firm which designed and manufactured *Pisces 1*, and told them of my anxieties about our RIPs and how the possibility of an embarrassingly useless summer trip could be avoided if *Pisces 1* was on board the recovery icebreaker. I was then invited to participate in a dive in Nanoose Bay the following week, when I could also brief their pilot, John MacDonald, on our RIP installations and what sort of hazards might be expected on dives in Arctic waters.

I survived the dive in the murky waters of Nanoose Bay with no external visible signs of my distress at being confined in a clammy steel ball, where I had no knowledge of its controls or instrumentation, and the significance of all the strange noises. A week later I was informed that IHL was definitely interested in my proposal and *Pisces 1* would be available during August and September, 1968. The cost estimate was $150,000, which would cover not much more than wages and expendables. I was told that this very low price included an assumed benefit to IHL from publicity they would expect from operating in the Arctic. By this time, CCGS LABRADOR had been assigned to us for RIP retrievals and would be available in Halifax, before it went north, for the usual installation of hydrographic winches and whatever else we needed. I was pleased that Captain Paul Tooke would again be in command.

How to raise the money was the next question. After seemingly endless phone calls to Arctic scientists I had met in the past, I was able to assemble a package of contributions from those interested in using *Pisces* in the coming summer. Contributions were promised from DREP (on my behalf, for under-ice acoustics and RIP recovery); from Dr Bernard Pelletier of the Bedford Institute of Oceanography (for submarine geology); from Dr Carlton Ray of Johns Hopkins University (for recording sea-mammal sounds and their ecology); and from R.H. Herlinveaux of the Pacific Oceanographic Group (for oceanographic work). The Arctic Institute of North America arranged the contract with IHL at the request of the US Office of Naval Research who were to fund Dr Carlton Ray. By that time, our scientific party included myself, as chief scientist, Tom Hughes, Dick Herlinveaux, Bernie Pelletier, Carlton Ray, and Ray Hammond (Carlton Ray's technician). The *Pisces* crew were to be John MacDonald (pilot), Al Trice, and M. Wilson.

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[25] A.R. Milne, B.R. Pelletier, and R.H. Herlinveaux, "A Research Submersible in the Arctic: Pisces 1," *Defence Research Establishment Pacific Report 69-1*, (January 1969).

[26] A.R. Milne, "A Small Research Submarine in the Arctic," *Journal of the Arctic Institute of North America*, Vol. 22, 69-70, (March 1969).

[27] Paul Tooke, "The Long Cold Summer," *Transport Canada*, pp 4-6, (January-February, 1969).

Recovery of RIPs and research using CCGS LABRADOR

The Canadian Coast Guard spent a considerable sum in constructing a steam-heated shelter on LABRADOR for *Pisces*, built to IHL specifications. In addition, IHL needed to have on board a launch for towing *Pisces* back to the ship after a dive, but all the LABRADOR had was a marginally suitable shoreboat. Enquiries revealed that the original launch on LABRADOR, when it was owned by the Navy, would fill the need but was being used for other purposes by the Navy. Our sister laboratory, DREA, in Dartmouth, convinced the Navy that our need was greater than theirs and the launch was reinstalled on LABRADOR. Finally, the RCAF would provide us with a C130 Hercules to fly *Pisces*, its operators, its spares, two tons of DREP scientific equipment, and our DREP scientific party from Vancouver to Thule, Greenland, to meet CCGS LABRADOR.

On August 11, our 'Herc' roared out of Vancouver with its 25,000 lb of cargo. After a refuelling stop at Namao we landed a day later in Thule where LABRADOR was already dockside. Carlton Ray and Ray Hammond had arrived earlier on a US Airforce flight. After spending a night in quarters at the Thule air base and taking in the nightclub atmosphere at the Officers Mess, we assisted loading our gear aboard LABRADOR while *Pisces* was reassembled and hoisted into its shelter and fastened securely into U-channels previously welded onto LABRADOR's deck.

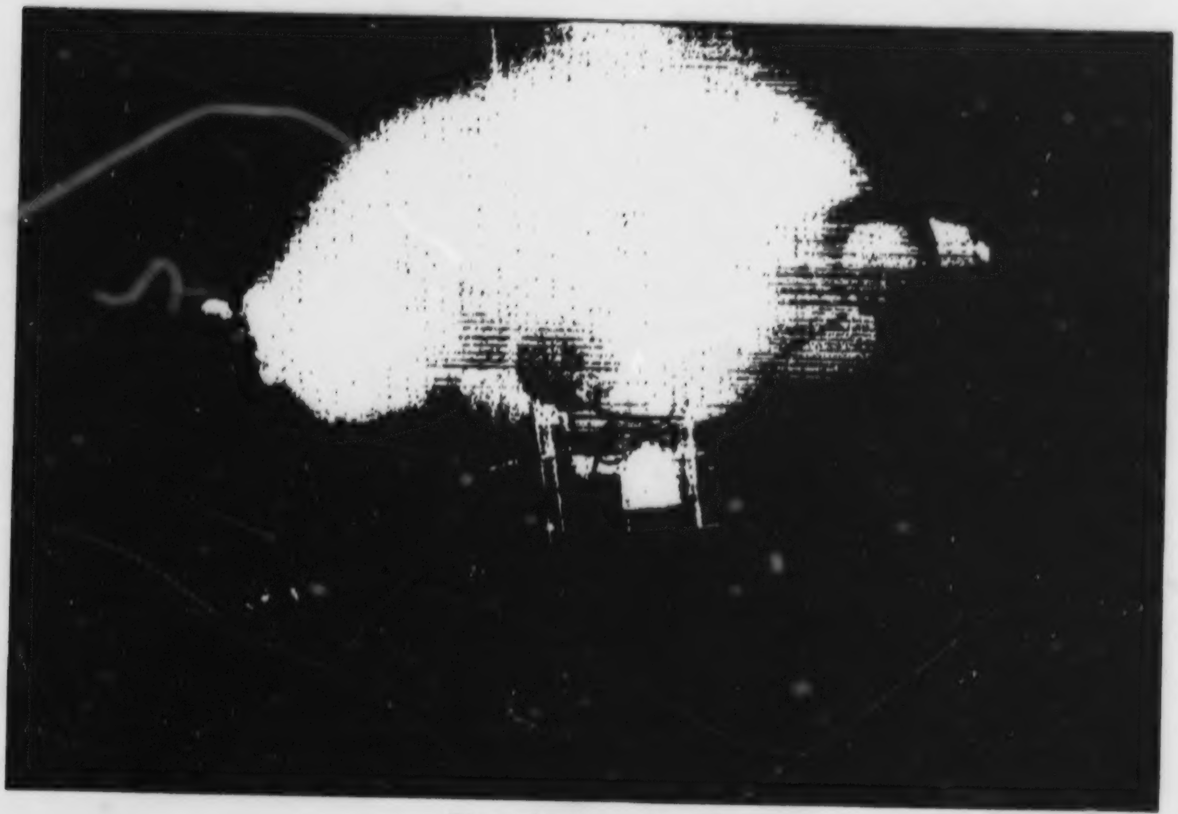
On August 13, we cast off from Thule and headed into northern Baffin Bay to the RIP located off Kap Parry, Greenland. Dense fog greeted us on arrival near the site so we had to wait for it to clear before the helicopter could look for the RIP's float and dye stain after the interrogation sounds set off the explosive bolt. The weather cleared the next day; the RIP was

Iceberg grounded on RIP in northern Baffin Bay

interrogated but our on-board hydrophone did not detect the expected sound from a fracturing explosive bolt. The problem was evident; a 53 m high iceberg, estimated to weigh 50 million tons, was grounded on the 430 m deep knoll where the RIP had been perched the previous year. The berg was rocking with a two-minute period, its potential instability making it far too risky to use *Pisces* for a possible RIP rescue. Sadly we abandoned the site—RIP indeed!

Our next RIP site was in Norwegian Bay but we took time to conduct scientific work on the way. We headed west toward Smith Bay and while crossing Baffin Bay, Dick Herlinveaux made four Nansen-bottle casts and Carlton Ray used the helicopter to observe sea mammals. By August 15, Captain Tooke headed LABRADOR southward breaking ice toward Cobourg Island at the mouth of Jones Sound. We went into Jones Sound the next morning where more bottle casts were made and biological observations recorded during helicopter flights.

On 16 August, Bernie Pelletier had the dubious honour of making the first dive in *Pisces*, to a depth of 366 m to take bottom samples and to observe the bottom topography off the southern shore of Devon Island. He was ecstatic on surfacing, claiming that his observations confirmed his theory regarding glacier gouging of Jones Sound. This dive did not have an auspicious beginning. The Navy's launch was found to be useless, its engine block having cracked from a failure to fill its cooling system with antifreeze. Pisces had to be towed to and from LABRADOR using the barely adequate shore boat. (After LABRADOR returned to Halifax, there was much finger-pointing as to assigning blame for damage to the Navy's launch. I was finally tagged, unjustly I think, but the politically correct response prevailed and



***Pisces* in Jones Sound**

DREP picked up the $1,200 engine replacement expense.) At the end of the day we headed for Norwegian Bay through Hells Gate and by morning were in 10/10ths ice under low stratus close to our next RIP site.

Tom and I helicoptered to Graham Island and placed our radar transponders next to the cairns we had built the preceding summer. LABRADOR was positioned over the RIP site. A fuel drum was set on the ice to mark the spot, then the ship spent a half day breaking up the ice within a circular area to make sure that the dye from the RIP's float could be seen if it surfaced under the ice. The helicopter was sent aloft, hopefully to observe the dye. With apprehension the RIP was interrogated. Ten minutes later the pilot had spotted green dye and LABRADOR, controlled by Captain Tooke, gently nudged aside broken floes to uncover the RIP's float to the accompaniment of cheers from the crew. The float was snagged with a boat hook and the RIP's polypropylene rope and following steel cable were wound on a winch which lifted the RIP to the surface. There, Ray Hammond in his wet suit, retrieved biological specimens stuck to the RIP and then attached the heavy cable of the boat crane to the RIP for its final lift to the deck. Tom disconnected the RIP's battery-pack from its electronics module, leaving an evaluation of its performance to dissection at DREP. Our transponders were then collected from Graham Island.

After such an uplifting day, I spent some hours in *Pisces* installing and checking out electronics in preparation for recording sounds backscattered from under the local ice from pulses emitted by a projector on the bow of the submersible. The next day, 18 August, *Pisces* with a safety line attached was lowered into a polyna with its pilot John MacDonald and myself inside. The safety line was reeled out as LABRADOR backed away, meanwhile keeping in radio contact until we were cleared to dive. Unfortunately, serious noise interference in my electronics resulted in that dive being aborted. Carlton Ray then got aboard and we dove 330 m to the bottom and took video and film records of the sparse bottom flora. In another dive, Bernie Pelletier collected bottom samples for geological analysis. Meanwhile, Dick was busy sampling the water column, coring the bottom and making plankton hauls.

On 19 August, we left Norwegian Bay en route to Jones Sound but not before Carlton Ray and Ray Hammond scuba-dove under the ice, hopefully, but not successfully, to photograph the resident but wary ringed seals. By the next day we were ploughing through heavy floes, stopping twice for Dick to make bottle casts. We were heading for Grise Fiord, which incises the southeastern side of Ellesmere Island, where narwhal were expected to be feeding. Captain Tooke anchored LABRADOR in dense fog a stone's throw off the Inuit settlement located on a bar at the mouth of the Fiord. Some of his crew were ferried ashore for a much deserved-break, and, of course, the scientific party also got ashore and photographed the spectacular scenery and chatted with the curious children. Following enquiries, we were told that a large herd of narwhal had swum into the Fiord that very day. Carlton Ray and Ray Hammond flew with Captain Tooke to the head of the Fiord where 50 to 60 narwhal were seen leaping and slicing through the water. Recordings of their underwater sounds were made in what turned out to be the highlight of his voyage according to an ecstatic Carlton Ray.

We rounded the east end of Devon Island on 21 August where recordings of ringed seal noises were made from the sea ice and then headed toward ice-capped Bylot Island, at the east end of Lancaster Sound, where Bernie Pelletier wanted to observe the undersea geology from *Pisces*. Unfortunately, there were heavy swells making it unsafe to launch *Pisces*. Bernie then decided that Pond Inlet's bottom would be of interest to him, whereupon we rounded Bylot Island into the ice-covered and iceberg peppered Inlet. Two dives were made in *Pisces* in ice-free water not far offshore of the settlement of Pond Inlet. The sea bottom was observed to be ploughed into deep trenches by icebergs and littered with pop-cans. Soon after we were hoisted aboard LABRADOR, a local hunter motored alongside and asked if we had seen any narwhal tusks, claiming that the bottom must be covered with them. One was found but could not be grabbed by the crude sampler on *Pisces*, its sophisticated manipulator arm not having been fitted at this time.

The next day, ashore in the settlement of Pond Inlet, we asked some of the hunters where the narwhals were likely to be seen. Following their advice, LABRADOR proceeded westward from Pond Inlet through Eclipse Sound and steered southward into mostly ice-free Milne Inlet where *Pisces* made two dives to the bottom to observe and capture bottom flora. Several flights were made onto ice floes for Carlton Ray to record biological sounds; other flights took Bernie Pelletier to places of geological interest. No narwhals were evident.

By this time, on 23 August, the unrecovered RIPs were uppermost in my mind so we headed toward Lancaster Sound northward through thick fog in Navy Board Inlet, Dick occupying four oceanographic stations en route. Heavy seas breaking over the bow of LABRADOR greeted us in the open water of the Sound where the RIP lurking there had to be temporarily ignored as we headed further west toward the RIP location south of Cornwallis Island. On the way six more oceanographic stations were made good and the recovery of that RIP proceeded as it should in calm open water. Two RIPs aboard, two more to retrieve!

At this point, Captain Tooke was called off our project to escort a freighter stuck in the ice while attempting to approach Resolute. Then on 28 August, the Irving Arctic, an ice breaker tug, was stuck in the ice while pushing an unwieldy barge toward Rae Point, the Panarctic Oil base on Melville Island. The barge had an experimental bow design, 'the Alexbow,' which

Melville Island Cliffs

like a plough was supposed to break the ice from its underside. Unfortunately the bow would steer the barge in the direction where ice would yield most easily, making it impossible to hold to its required course. The captain of the tug confided that in open water the barge attempted to mimic a submarine. Scratch that idea! LABRADOR, by breaking a clear path, got it on its way.

On August 29th, LABRADOR was relieved of its escort duties and we headed toward our RIP site off Melville Island. There was a grand stretch of open water from the shore to just south of the RIP site, so *Pisces* was prepared for a dive to the bottom to photograph the RIP and to aid in its recovery if necessary. Coded sounds, sent from the small recovery transducer hung over the rail, were followed by a satisfying clunk heard from the RIP's explosive bolt, and ten minutes later its float was bobbing on the surface. *Pisces* was launched with me inside, and John MacDonald carefully manoeuvred *Pisces* to follow the float's polypropylene rope down to the RIP. The water was remarkably clear. At a depth of 700 ft I could see the banana shape of LABRADOR's hull and, to the south, seals swimming under a nearby ice floe. The eerie shape of the RIP loomed in *Pisces*' lights at a depth of 1,000 ft. Even after a year there was virtually no marine fouling. Many photos later, we ascended, leaving the recovery of the RIP to be made normally. As it turned out, the recovery had all the characteristics of an impending disaster. A large polar floe was inexorably approaching LABRADOR while the recovery winch had yet to wind on the RIP's steel lifting cable. As the steel cable was pulled to the surface by the polypropylene line and wound on the winch, LABRADOR was being pushed off its position by the heavy floe. Finally the RIP was lifted off the bottom but not before it had sustained damage by being dragged along the seabottom upside down. Fortunately its pressure cases remained undamaged preserving its records.

That night, at dinner with Captain Tooke, Dick said he wanted to make three oceanographic casts to the southwest across Viscount Melville Sound. I also wanted to make under-ice acoustic backscattering recordings using *Pisces*, having by this time solved my noise interference

RIP on the bottom of Viscount Melville Sound observed from *Pisces*

problem. We discussed an additional investigation knowing that to the west, Mercy Bay, in northern Banks Island, was where Captain M'Clure's ship, the INVESTIGATOR, had been abandoned in 1853 after wintering there for four dismal years. Presumably its wreckage would reside on the bottom of the Bay. "Wouldn't it be a discovery of major historical interest if it could be photographed in its resting place using *Pisces*?" Needless to say, this wishful thinking was soon frustrated by unco-operative, heavy, polar ice floes and severe weather—perhaps conditions similar to those which had kept INVESTIGATOR trapped for so long. After Dick's three stations had been occupied, LABRADOR was forced to break a return path northeastward eventually encountering a 'safe' polyna in first-year ice where *Pisces* was launched, tethered by a safety rope, for me to record under-ice acoustic backscattering sounds. The polyna promptly began to shrink; *Pisces* was recalled, my work unfinished. By 2 September, I finally got some recording from under first-year ice at the edge of a stable polyna.

The next day we were off Cape Providence, Melville Island, where Bernie Pelletier wanted to investigate the bottom geology and collect some rocks. For this dive the $50,000 stainless steel manipulator arm he used for grabbing rocks and depositing them in a basket on *Pisces* unaccountably dropped to the bottom in 200 m of water as the submersible surfaced. The position of LABRADOR was quickly fixed, while *Pisces* prepared to dive to search for the arm but meanwhile a large polar floe drifted over the site. The loss of the arm was disturbing, not only because of its value, but because the loss of weight resulted in *Pisces* ascending at an uncontrolled rate to the surface. If it had surfaced under a polar floe, its exact location would have been unknown, making a rescue using the icebreaking capabilities of LABRADOR extremely hazardous.

Both diving in *Pisces* and flying were cancelled as polar ice continued its ponderous drift and low stratus and fog enveloped LABRADOR. We stood by, waiting to recover the valuable arm and for visibility to improve, but to no avail. Our vigil was terminated on 6 September when LABRADOR was called to escort a supply vessel into nearby Rae Point for Panarctic Oil and was then to proceed to Resolute for further escort duties. En route, the helicopter was used almost continuously for making geological and biological observations, once landing on the ice where harp seal sounds were recorded. By mid-day on 10 September, we were relieved of escort duties and eager to recover the remaining, hopefully intact, RIP that we had bypassed earlier in Lancaster Sound. On the way east, the helicopter made biological flights into Gascoyne Inlet and Radstock Bay, in southwest Devon Island. We arrived in calm, open water and flawlessly retrieved our last 'live' RIP.

Captain Tooke concurred with our scientific plan to continue to use the helicopter and *Pisces* for geological and biological observations and opportunistically to collect oceanographic data. One aim, given time, was to venture into northern Baffin Bay and use *Pisces* to look at the remains of the RIP that was squashed by an iceberg off Kap Parry. As it turned out, that aim was frustrated by reports of heavy seas in Baffin Bay, so we remained to work in the protected waters of Pond Inlet, and south of there, in Milne Inlet and Koluktoo Bay. Several dives were made in Pond Inlet and on one of those dives I was on, we almost collided with a sluggish, 20-ft long, Greenland shark. In the interest of science, of course, we chanced to fish for Arctic char in a rushing stream that flowed into Koluktoo Bay. We all were lucky, catching several 6-lb fish, which were put in LABRADOR's freezer and eventually flown in our homeward bound C130, stored within the outer shell of *Pisces*. In Koluktoo Bay were numerous ancient remains of whale-bone littered dwellings. The grassy vegetation was lush—a place of rugged beauty.

Time was running out. By 16 September we were in heavy seas proceeding eastward in Lancaster Sound, still hoping for calm diving seas off Kap Parry. Seas did diminish the next day but a heavy swell at the now iceberg-free RIP site prohibited launching *Pisces*. We set-to packing up our equipment for off-loading at Thule's dock, and the ship's radio alerted the RCAF of our arrival time of September 19th. By the 20th we were airlifted back to Vancouver, ending an eventful, never-to-be-forgotten, forty-day voyage on LABRADOR.

What the RIPs revealed

After the four RIPs were trucked from Vancouver in late September, their dissection began with some anxiety expressed by those in DREP who had invested so much time in their design, construction and testing, and by those scientists who could hardly wait to have their expectations fulfilled. Here is what had happened: The noise spectra available amounted to about one-third of what might have been available had all five RIPs operated perfectly and been retrieved. Component failures tended to occur later in the year resulting in good coverage in the previously unmeasured fall and early winter. Other than the loss of the iceberg-trashed RIP in northern Baffin Bay, most data were lost due to faulty underwater electrical cable connectors which leaked after their long immersion. Nevertheless, we were extremely pleased with the variety and quality of the under-ice sound spectra recorded which not only bridged gaps in our knowledge but also revealed unanticipated effects of seasonal changes on underwater noise; for example, in Viscount Melville Sound when open water became covered with moving ice, and then when that ice became landfast. Features of RIP-recorded underwater noise are described in the plethora of reports this program spawned. [28,29,30,31,32,33]

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[28] A.R. Milne and J.H. Ganton, "Diurnal Variations in Underwater Noise beneath Springtime Sea Ice," *Nature*, Vol. 221, 851-852, (1969).

[29] A.R. Milne, "The Transition from Moving to Fast Ice in Western Viscount Melville Sound," *Journal of the Arctic Institute of North America*, Vol. 1, No.1, 45-46, (January 1970).

[30] A.R. Milne, "Predictions of Temperature in Snow-free Sea Ice with Hourly Changes in Atmospheric Heat Fluxes," *Defence Reseach Establishment Pacific Report 71-3*, (1971).

[31] A.R. Milne, "Thermal Tension Cracking in Sea Ice," *Journal of Geophysical Research*, Vol. 77, 2177-2192, (1972).

[32] J.H. Ganton and A.R. Milne, "Ambient Underwater Noise in Arctic Waters: A Synopsis of Time-series Spectra in the Canadian Archipelago," *Defence Research Establishment Pacific Report 72-3*, (June 1972).

[33] A.R. Milne, "Wind Noise under Winter Ice-fields," *Journal of Geophysical Research*, Vol. 79, 803-809, (February 1974).

M'Clure Strait and Melville Island, 'Icepack 4/69'

Plans to test the acoustic stability at long ranges under landfast sea ice in the springtime

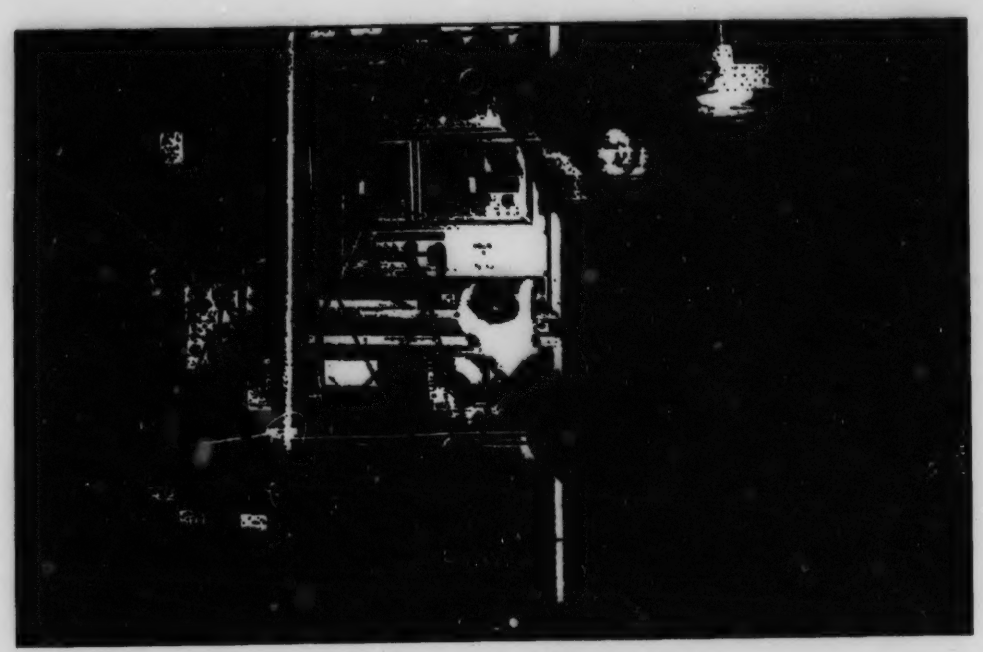
In the spring of 1966 and 1968, we measured how closely a series of acoustic pulses transmitted under landfast ice would remain identical to each other when received at distant hydrophones. Evidently, the short range media through which the pulses were transmitted were very stable, successive series of pulses changing only marginally as the tides slowly raised and lowered the ice cover. The question remained whether this would be the case at longer ranges. Therefore, over the winter of 1968-69, we made plans to return to M'Clure Strait at the same time of year and test the acoustic stability over significantly longer ranges—at ten, twenty, and thirty nautical miles. At these distances, radio telemetry of sounds detected by ice-mounted hydrophones was a must. Our sometimes dismal experience with UHF ice-level telemetry made it necessary that we have our receiving antennae at a high cliff-site on Melville Island. We already had two good tent shelters. The 'octagon,' perched high on the cliff edge, would house the electronics to record telemetered pulses. The 'gothic,' sitting on the sea ice, would contain the pulse generator which would drive the underwater sound projector. Its series of pulses would be telemetered directly to the cliff-site to enable comparisons to be made with pulses telemetered from distant hydrohones.

Over the winter, telemetry links, hydrophone systems, the icecamp's pulse generator, power amplifier, and underwater sound projector were assembled and tested. Ice drills, 115 vac generators, and innumerable spares were listed and loaded in numbered fiberglass boxes. Rations for two camps were carefully selected after much consultation and boxed in 'dry ice.' Our field party to man the icecamp included Tom Hughes, Borg Haagensen, and Warren Wall. (Borg had been yearning to get back to Arctic work for some time. Before coming to DREP, he had been on North Greenland expeditions with a Danish research team.) The cliff-top camp would be manned by myself and the youthful-looking John Ganton, who dubbed himself 'the boy explorer.' I knew that Polar Shelf would provide us with heating and generator fuel as in the past. Explosives, left over from earlier field trips, were already cached in Mould Bay. These would be needed to blast a hole big enough to insert the sound projector through the ice.

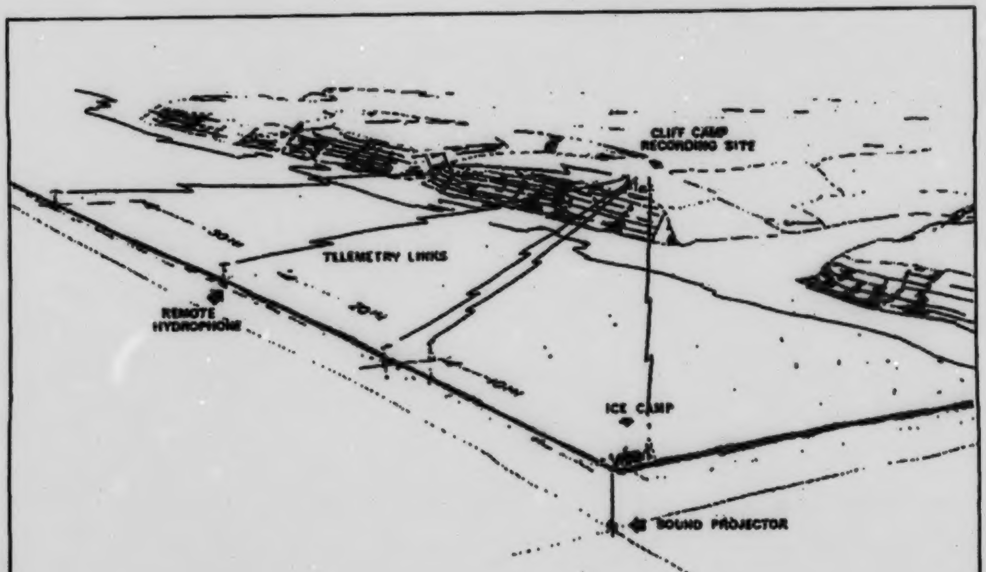
The usual requests were made to Air Transport Command and the Polar Shelf Project with the usual positive responses. On April 9, we left Patricia Bay Airport on our heavily loaded C130 Hercules, headed for Mould Bay, Prince Patrick Island, the western-most Polar Shelf base, expecting to be in the Arctic for five weeks.

Bumpy landings and local wildlife

Our first priority, after unloading our cargo at Mould Bay, was to take an Otter load the 135 nm distance to the cliff top facing M'Clure Strait near Cape James Ross, just south of Liddon Gulf. Affable Frank Hunt, the Polar Shelf field director, soon got John and me on our way. With a full Otter load, we arrived near our chosen site to find that a landing was indeed possible though likely very bumpy on the uneven snow field. The pilot made several low approaches and finally landed in what seemed like a controlled crash. After using almost full power, the skis breaking through snow ridges, we taxied to within 50 m of the cliff edge, unloaded our cargo and then headed back to Mould Bay after taking off on a rolling down-slope. Our next task was to use all our manpower to set up the icecamp with its sound projector and mount our hydrophones—at distances of ten, twenty and thirty nautical miles from the



John Ganton at the cliff-top camp



Acoustic stability experiment in M'Clure Strait

icecamp. We wanted to align hydrophone locations with the axis of M'Clure Strait, but fifteen miles off the cliff-face below the cliff-camp. The mostly first-year ice afforded us good leads to land on, and use of the Decca-Lamda navigation aid in the Otter made positioning the hydrophones relatively easy. A week later, after many other flights and ice landings, all was in

Visitors to the cliff-top camp

readiness for John and me to setup our cliff-camp. This proceeded without a hitch, the 'octagon' being a comfortable abode, and we were gratified that the electronics survived the bumpy Otter landings. It took some time to set up our VHF antenna for our SSB voice link and five telemetry antennae (one pointed at the invisible icecamp, two to the two tandem hydrophones at ten miles, one to the hydrophone at twenty miles, and one to the thirty-mile hydrophone). Wooden pins were inserted in holes hand-drilled into the permafrost beneath the snow in order to make sure that the next storm would not flatten the antenna farm on our vulnerable cliff-edge site.

We settled down to a daily routine despite the lack of darkness and had time for local walks. A small herd of eight muskox grazed nearby on the sparse vegetation they had uncovered by scraping away the crusty snow. As we approached them they would slowly form their defensive arc. Borg reported that two curious wolves were sniffing near the icecamp close enough to be photographed. Our cliff-top site was a near vertical 300 m above the sea ice, the latter having thrown up a rim of ridges at the base of the cliff. It was a spectacular location, usually so quiet I could almost hear my thoughts—or so it seemed. At times the ice on M'Clure Strait was often obscured by blowing snow while at the cliff-top we had sunny, calm weather as we gloatingly informed the storm-bound icecamp crew.

By early May, all our tapes were stuffed with data and it was time to break up our camps, collect our telemetry transmitters connected to the expendable hydrophones and head for home.

Ice-drift in Parry Channel, 'Icepack 4/70'

Special sonobuoys constructed at DREP

The long-range under-ice acoustic stability tests of April, 1969, showed a very stable underwater environment. However, in Parry Channel (otherwise known as the Northwest Passage) it would be necessary to know the seasonal duration of landfast ice to assess its applicability. Pertinent to solving this problem we had been toying with the feasibility of air-dropping a pattern of ice-piercing sonobuoys in Parry Channel as a means of providing seasonal and area-extended ambient noise data. These sonobuoys would be monitored every one to two weeks until most of them would succumb to crushing or sinking. If at the same time their positions were recorded, we could determine when they would begin to move as the ice freed itself from land and moved with winds and currents. However, ice-piercing sonobuoys had not yet been developed. The next best scheme was to construct home-made, long-life sonobuoys using parts from production models in current use, and manually install a pattern of these instead. These we dubbed 'sono-drift buoys.'

Twenty-two of the home-made sono-drift buoys were constructed at DREP. Each was fifteen feet long and three inches in diameter with a flotation collar, an antenna on top, and a hydrophone suspended beneath. The active radio receiver inside would switch on a transmitter when it sensed a signal from an overflying aircraft. The aircraft would then record the telemetered underwater ambient noise. At the same time the aircraft could locate its position and be able to track its drift—and incidentally find out when it got crushed or overwhelmed by moving ice.

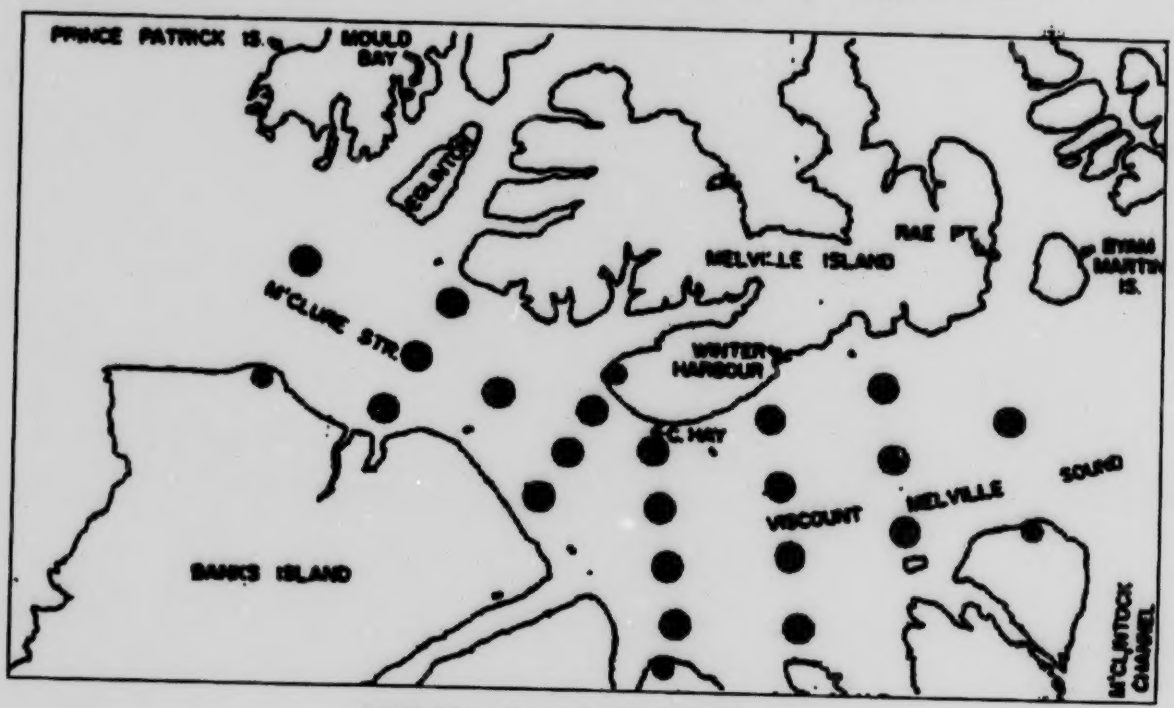
Inserting sono-drift buoys in western Parry Channel

Parry Channel had been the scene of the travels of the American oil tanker MANHATTEN in the summer of 1969 when it broke its way west through Viscount Melville Sound, was rebuffed by the heavy ice in M'Clure Strait, and then turned south through Prince of Wales Strait. Its travels renewed the sovereignty debate in Canada and I'm sure had a lot to do with the prompt support we got from the Canadian Forces, who flew us north in their C130 Hercules and later overflew our buoy positions on 'sovereignty' flights from April to September 1970 using Argus aircraft based at Comox.

Our installation field crew in the spring of 1970 consisted of John Ganton, Tom Hughes and myself. Stan Toole, a Canadian Forces officer, seconded to DREP, undertook to do most of the interrogating and positioning of the drift buoys. John Ganton and Tom Hughes took two of the buoys with them in February to Resolute and installed them in the offshore ice to undergo testing, hoping that no 'glitches' would occur in their operation and in aircraft interrogation procedures. They functioned beautifully. Since we had only a total of 22 sono-drift buoys, and two of these were used off Resolute, our plan was revised to install the remaining 20 buoys in a denser pattern in Western Parry Channel, extending throughout western Viscount Melville Sound and M'Clure Strait. Anticipating successful tests of the two buoys installed in the ice off Resolute, I requested accommodations for our DREP crew at the Panarctic Oil Company base at Rae Point, southeastern Melville Island. They agreed to support us, as well as the Polar Shelf aircraft, normally based at Mould Bay, which would be used to land on the ice to install the buoys.

Winds are the prime driving force behind drifting ice and can be deduced from atmospheric pressure data. To supplement distant weather station pressures, four recording barographs, were placed on surrounding islands. Most of the sono-drift buoys were installed using the Otter landing on frozen leads in first-year ice but where multi-year floes existed Polar Shelf's 204B helicopter had to be used. Each Polar Shelf aircraft was equipped with Decca-Lamda navigation electronics, which provided accurate buoy positions.

After the work of installing the sono-drift buoys had been completed by mid-April, John Ganton and I were flown by Otter to Mould Bay and then by a re-supply C130 to the Canadian Forces Station at Alert, at the northern end of Ellesmere Island. At Alert, we were to make preparations for our next April's work in Robeson Channel (named *Icepack 4/71*).



Initial location of sono-drift buoys

Argus flights to overfly and interrogate the drift buoys began in mid-April.[34] At that date, 17 buoys responded, three having failed from bear or seal assaults or electronic problems. Interrogation flights continued at two-week intervals but changed to weekly as the buoys drifted more rapidly by early summer. Flights ceased by mid-September when all the buoys installed in first-year ice had died while only three remained alive in polar floes. The Argus aircraft, not having a precise electronic navigation system, would electronically locate a virtually invisible drift buoy and be itself positioned using its radar map of echoes from the islands on either side of Parry Channel. The most rapid ice drift occurred in a westerly direction at the west end of M'Clure Strait.

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[34] R.L. Verrall, J.H. Ganton and A.R. Milne, "An Ice-Drift Measurement in Western Parry Channel," *Journal of the Arctic Institute of North America*, Vol. 7, No. 1, 47-52, (March 1974).

The four barographs provided no records at all, the insulation on their electrical cables from external batteries having provided a tasty meal for wandering foxes. Calculations of ice drift based on winds derived from distant weather station atmospheric pressures yielded some credibility to the ice drifts observed. Under-ice noises telemetered from the buoys were a valuable addition to our bank of Arctic acoustic data.

Installing a sono-drift buoy in first-year ice in Parry channel

3. FLUID DYNAMICS

H. L. Grant and B. A. Hughes

Turbulence

General

Bob Stewart arrived at the laboratory at the beginning of August in 1950 with no previous knowledge of naval warfare or of underwater acoustics, the area that he was employed to work in. He did come with a superb general knowledge of physics and, most importantly, with an open and inquiring mind. His PhD research had covered important topics in the basic physics of turbulence, then principally associated with aeronautical problems, and he soon realized that turbulence in the ocean was a likely cause of fluctuation in the sound field. The existing theory on sound fluctuation in a turbulent medium was inadequate and Bob tried to improve on it but the problem was found to be intractable.

He also saw, however, that the turbulent wake behind a submarine might be detectable and that, if the turbulence in the wake persisted for a long time, and if it were feasible to detect the wake, the search would be for a line rather than a point. Having an additional search technique of this type would greatly alter the tactical problem faced by ships that currently used short range active sonars.

As early as 1952 the laboratory began a research program to investigate turbulence in the sea. At that time practically nothing was known about small scale motions in sea water other than surface waves and even these obvious features of the sea were very imperfectly understood. This state of knowledge could be contrasted with the situation in the atmosphere where small scale features such as the gustiness of wind and the patchy structure of many cloud types were familiar and of great known importance to activities such as flying and predicting the dispersal of pollutants.

It became evident later that internal waves were another type of small scale motion that was ubiquitous in the ocean and of significance to ASW. After 1965 these waves became the main subject of research in the Fluid Dynamics Group.

Characteristics of turbulent flow

The principal characteristic of turbulent flow is that the velocity of the fluid contains a component which is a random function of space and time. It is a special type of randomness because, in an incompressible fluid such as water, the fluid must be continuous and so water flowing out of an element of space must be balanced by water flowing into that element, perhaps from some other direction. After the randomness, the most fundamental characteristic of turbulent flow is that the fluctuating part of the velocity contains kinetic energy which is put into the turbulence by whatever stirring action created it in the first place. Unless some agency continues to stir the fluid the energy of the turbulence will decay with time due to the action of viscosity in the fluid.

In the ocean there are other important variables that also display randomness when the water is turbulent. The most obvious of these are temperature and salinity because in general these properties of the water are functions of depth and since turbulence is a three dimensional phenomenon it must stir up water from at least a small range of depths. The result is that the temperature and salinity of the water will display small fluctuations in time and space and eventually, if there is no further stirring, these will be wiped out by thermal conduction and by the diffusion of salt just as the velocity fluctuations will succumb to the effects of viscosity.

None of these quantities had ever been measured successfully in the sea on the fine scale and with the high frequency response necessary to describe the properties of turbulence. Although it was by no means clear how the necessary technology could be developed, Harold Grant was sent off to Cambridge in 1954 on a DRB scholarship to do a PhD in turbulence research, and Stewart ordered a water tunnel from a German firm to be placed in a basement being excavated under the south end of the building.

The research that followed was centered around the development of two instruments that used thin film sensors to measure velocity and temperature fluctuations in turbulent sea water over very small spatial scales and with the necessary very high frequency response.

Personnel and laboratory facilities

At first the Group was rather ill-defined with most of the technician strength drawn from the Engineering Section, notably Hugh Derricks and Dave Edwards. When Harold Grant returned in 1957 the full time members of the group were Tony Moilliet and Blyth Hughes and shortly afterward Jim Waterman joined as our first technician. By about 1961 the Fluid Dynamics Group consisted of Harold Grant, Blyth Hughes, Tony Moilliet, Bob Chappell, Dick Anderson and Tony Pastro, the basic group that stuck together until about 1975. (Blyth had gone to UBC in 1958 and returned with his masters degree in 1960. From late 1961 until 1964 he was again away on a DRB scholarship while he completed a PhD at Cambridge.) Bob Stewart had moved to the faculty at UBC but remained closely associated with the Group as a consultant and made frequent visits to Victoria. For the instrumentation, the group depended heavily on Harry Davidson, Don Evans, Graeme Dennison and Bob Weir but the temperature bridge was Bob Chappell's first major instrument development.

Although the objective was to make observations at sea it was necessary to build up special laboratory facilities for the development and calibration of a variety of sensors. The basement lab had two water tunnels, the "Big" tunnel built for us by Kempf & Remmers in Germany, and the "Small" tunnel borrowed from the David Taylor Model Basin in Washington. The big tunnel held about 4,000 gallons of water and was made of stainless steel with the idea that sea water could be used in it. In fact sea water would turn a rusty brown in about 24 hours due to corrosion of the stainless steel which Ralph Barer concluded was not heat treated properly. The tunnel did have a very low turbulence level in the working section, and after Bob Chappell made an ingenious speed control that really worked, Graeme Dennison made windows that could be readily removed and Tony Moilliet constructed a huge vacuum system to control the pressure, it was an excellent calibration facility for a variety of velocity sensors. It was principally used for determining the sensitivity and frequency response of thin film velocity probes and for the calibration of current meters. The frequency response of velocity probes was determined by an electromagnetic vibrator which applied a sinusoidal motion to the probe in the steady water flow of the tunnel.

The small tunnel was made of Plexiglas and actually could take sea water which was obtained, when required, from the laboratory sea water plumbing system. We built a heat exchanger so that the temperature could be accurately controlled and it was used, among other things, for calibrating temperature probes and thermistors and for determining the temperature sensitivity of velocity probes.

The other major lab facility at this time was the "plume tank." This was an original device for determining the frequency response of temperature probes. It was devised by Andy Fabula of the Naval Undersea Warfare Center, Pasadena, CA, who spent a year with us as an exchange scientist. In this tank a temperature probe was passed at known speed through a convective plume of warm water above a heated resistance wire. The temperature structure in the plume was known from fixed temperature sensors and Andy was able to verify a heat conduction model that he had devised for the probe. By assuming a sinusoidal profile for the temperature structure in the plume, and using his theoretical model, the frequency response of the temperature probe could be calculated. Blyth Hughes later refined this process to compute the frequency response directly from the power spectrum of the plume profile. This computation was programmed on the Sigma 7 by Blyth Hughes and Dick Anderson and the plume tank became one of the first instruments in the lab that absolutely depended on digital computery for its operation.

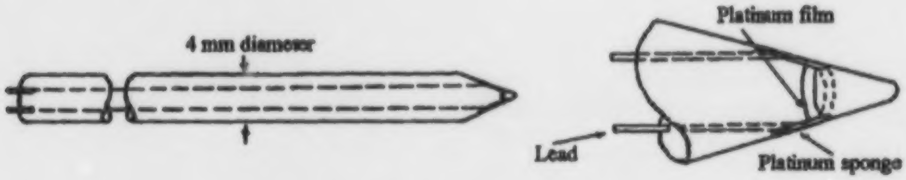
The velocity sensing probes

There was no instrument available to observe small scale velocity fluctuations in sea water; current meters of the day could only record long-term averages of flow velocity and direction. The instrument used to observe fluctuating velocity in wind tunnels was the hot wire anemometer in which the sensor is a tiny electrically heated wire (diameter typically 3μm) whose temperature, and hence resistance, depends on the velocity of the flow past it. Bob Stewart attempted to adapt this device for use in the sea but even with much more robust wires the exercise proved to be a lesson on how to catch stringy forms of plankton and seaweed. In 1955 Bob was seconded to The Institute of Oceanography at UBC while still a DRB employee and Ashton Patterson was hired to carry on with the hot wire work.

By late 1957, after Harold Grant returned from Cambridge, a company named Lintronics Inc had developed a thin film flowmeter using a platinum film plated on a small glass wedge for use in water. This overcame the weakness of tiny wires in water but it was still a great plankton catcher. The company produced a film on a conical substrate that was less prone to plankton catching than wedges but in spite of the their claims none of their systems would work in sea water. Moilliet and Grant set out to devise a sensor that would. After some fruitless experimenting they were surprised to learn from Jack Carson that platinum dissolves readily in the presence of chlorine ions and DC voltages. With that knowledge it was obvious that the film had to be heated with alternating current if we were to work in sea water. It seemed important to ensure that the delicate film would not burn out if it became thermally insulated by a coating of plankton or seaweed so we required a Wheatstone bridge operating at 7.5 kHz and with feedback to maintain the film at constant temperature. This complex device designed by Don Evans used the new transistor technology and eventually, when we worked in deep water, found its place beneath the surface in the towed fish that carried the sensors.

The output of a constant temperature flowmeter bridge is inherently non-linear, i.e. the sensitivity to velocity depends on the mean velocity. Harry Davidson solved that problem for us with a box called the linearizer which corrected the output of Don's bridge using the non-linear characteristics of a vacuum tube. Unstable as that might sound to a modern engineer, the linearizer served us well and lasted well into the digital age. A lesser device might have been thrown over the side years before because of an unfindable intermittent fault, but in this case everybody learned how to rap the front panel with a knuckle in just the right spot whenever required.

The progress of the electronics was relatively straightforward although there were constant changes to accommodate changes in the sensing probes. The development of probes was another matter. At the best of times it was only one step back for every two steps forward. The big problem with the velocity probes was instability of the electrical properties of the evaporated films when heated in sea water. After we gave up on Lintronics, the probes were made for us by Prof Lawrence Young of UBC who did some significant research on the bonding of the evaporated platinum film to the glass. After every modification of the manufacturing process, probes had to be put through extensive tests in the water tunnels to measure their sensitivity, frequency response and stability. Even when we found a good one after hours of tests we could never be sure that it would not develop an open circuit the next hour or the next day. As delivered, the resistance of the films was not stable enough for use as velocity sensors but Tony Moilliet devised an annealing procedure that markedly improved the stability of those probes that survived the procedure. The theory of this process could be placed in the category of folklore but it provided a barely adequate number of usable probes.



The hot-film probe. The diameter of the cone is about 0.5 mm at the film.

We started working with thin film sensors in early 1958 and as soon as we got some that were stable enough to survive a water tunnel calibration we began towing them to try first to get some idea of the level of turbulence signal that we might find in the real ocean. Actually the real ocean would have been too big a step from the water tunnel so the sheltered waters inside of Vancouver Island were what we called "sea" at that stage. We obtained an old navy paravane and modified it with lead ballast for towing with a steep wire angle from one of the minesweeping davits of the OSHAWA. This was the beginning of a long tradition of handling delicate instruments with heavy and not very delicate over-the-side gear.

The frequency response of the thin film sensors was flat out to about 1 kHz which was necessary in order to sense velocity structure down to millimeter scales when they were towed at the minimum ship speed which was usually about two knots. This was several orders of magnitude higher than the response of any systems previously used in the sea but they were never very stable so it was always prudent to run them beside other sensors that were reliable if not so fast. We were able to obtain small commercially manufactured glass coated thermistors with a time constant of about 20 ms which we used as a standard for temperature measurements. For a velocity standard John Parker made current meters with a low inertia propeller driving an optical chopper. Bob Chappell designed the electronics for both of these instruments.

The energy spectrum of the turbulence

As a first objective we set out to measure the spectrum of very energetic turbulence. There were several reasons for this. One was that we were uncertain of the noise level of our instrument and to distinguish noise from turbulence which was also a random signal we needed a good strong signal for tests. Another was that there had been a theoretical prediction of the spectrum of turbulence at very high Reynolds number floating around unverified for about twenty years because the critical test could not be done in a wind tunnel. A high Reynolds Number flow is one with large physical dimensions, high speed and low kinematic viscosity. Such flows occur in the atmosphere and the ocean. We could easily find strong turbulence in the inside waters but these were often pretty wild places in which to operate a ship. We once persuaded the captain of the OSHAWA to stick his bow into Dodd's Narrows against a full tide and be flushed out backwards. We thought that was fine but for some reason he was unwilling to try it again. Another captain flatly refused to tow our probes in Aaron Rapids. Eventually we settled on Discovery passage as a place to work and as long as we stayed away from Seymour Narrows there was an acceptable balance between our desire for lots of action and the captain's concern for the safety of his ship. There was still plenty of action and we were once carried over the Wilby shoals, destroying our probes on the bottom. We can remember Captain Cassidy's relief when our equipment broke down and we had to stop work at 0200 on a dark and rainy night when he had been making two knots through the water and two knots astern with respect to the land, all this amid a collection of out-of-control fish boats and log booms.

Deploying the paravane from the quarterdeck of OSHAWA

Discovery Passage, where the mean flow was straight for several miles, turned out to be an excellent example of the type of turbulence we were trying to observe. With a Reynolds number of 10^8, it is an almost unique situation. Bob liked to point out that interstellar space with its vast dimensions has a lower Reynolds number than Discovery passage.

As we began to get real signals on the velocity sensor it soon became obvious that the switch from hot wires to thin films on cones had not removed the plankton problem, it just turned up in different ways. The first thing that was obvious was that in addition to the broadband turbulence signal which we could see in Discovery Passage there were frequent large spikes that also appeared in the relatively quiet coastal inlets. These were due to plankton particles that either struck the probe or came close enough to modify the boundary layer over the film. Every so often there would be an event in which the sensitivity of the sensor decreased abruptly and mean velocity or towing speed indicated by the film decreased. This meant that something was adhering to the probe and our only remedy was to call out the crew, haul up the paravane, untying the electrical cables from the towing wire as it came in, remove the probes, rinse them off in the sink and then reverse the whole procedure putting it back over the side again. Even when we got good at this the minimum time was about 30 minutes.

If the mean time between these events was much less than 30 minutes, as it often was, then the operation became very inefficient and it was impossible to get data samples of an adequate length or to work effectively on other kinds of troubleshooting. These problems led us to abandon most attempts to make measurements in the summer.

Working in the winter, and with practice on maneuvering in Discovery Passage, we began to observe occasional periods of several minutes duration when the towing speed and direction were reasonably constant, the plankton hits were not too frequent, there were no recording gain changes, calibrations or other interruptions. It looked as though we were observing a real turbulence signal and by constantly listening to it on a loudspeaker we learned to distinguish between turbulence and the various kinds of noise that looked much the same on the oscilloscope. The objective at this point was to determine the spectrum, i.e. the distribution of the kinetic energy associated with the fluctuating velocity as a function of the frequency of the signal. Frequency in turn could be associated with the size of "eddies." The energy falls off very rapidly with frequency and since this was in the days before digital recording or analysis we had to devise methods of pre-whitening the signal to stay within the dynamic range of the tape recorder. Power spectrum analysis was done by playing the signal back at several tape speeds through a series of electronic filters and determining the power with a thermojunction detector.

Great care had to be taken to get reliable and reproducible results with this system but by May of 1959 we had obtained what we felt was a satisfactory sample in Discovery Passage, and the first spectrum of very high Reynolds number turbulence was published in a letter to Nature in September of that year. In February of 1960, working near the annual minimum of plankton concentration we obtained enough reliable data to form the basis for an extensive paper on the spectrum of turbulence in Discovery Passage. This paper, which attracted wide international attention, was published in 1962 and verified the theoretical form of the spectrum which had been published twenty years earlier. Having thus established the spectral nature of the random turbulence signal, it was then possible for us to quantitatively distinguish it from random noises such as probe vibrations, effects of plankton impacts on the sensor, electronic noise, etc.

About this time there were two significant improvements in our instrumentation. Graeme Dennison designed the probe washer which directed a jet of water from a pump in the paravane over the point of the probe to dislodge whatever was adhering to it without bringing all of the gear up on deck. We also discovered that the glass probes had resonant modes of vibration which were a frequent source of noise in the velocity signal. These were suppressed by potting most of the glass tubes in brass ferrules to provide stiffening.

Small scale temperature structure

As mentioned earlier, it was anticipated from the beginning that temperature and salinity would show random characteristics in a turbulent wake and, in principle, either one could serve as an indicator of the presence of a wake. Temperature is the easiest of these to observe and a thin film resistance thermometer was developed to respond to temperature fluctuations down to millimetre scales. The principal problem with this sensor arose because the film could not be electrically insulated from the water without insulating it thermally in a way that would destroy its frequency response. The resistance of the film had a sensitivity to the conductivity of the water which in turn was dependent on both salinity and temperature. For this sensor Bob Chappell designed a remote controlled self-balancing AC bridge in which the conductivity response was bucked out using a third electrode on the opposite side of the bridge to the resistance thermometer.

Again there was an initial problem of distinguishing the wanted random signal from noise and again there existed an unverified theory predicting the form of the spectrum of temperature in high Reynolds number turbulent flow. Although the first version of this instrument was towed in Discovery Passage in 1960, it was not until 1962 that we obtained data from which we could calculate a reliable spectrum. The problems with stability of the platinum film were not as severe as those with the velocity probes but many hours of patient water tunnel work were required as the design was developed to minimize the sensitivity to water conductivity. Andy Fabula devised the method of determining the frequency response of the films. We delayed publication of the first temperature spectra for several years because of peculiarities of some of the associated velocity spectra (which we never did fully resolve.) but in spite of this the results were still novel and of general interest when published.

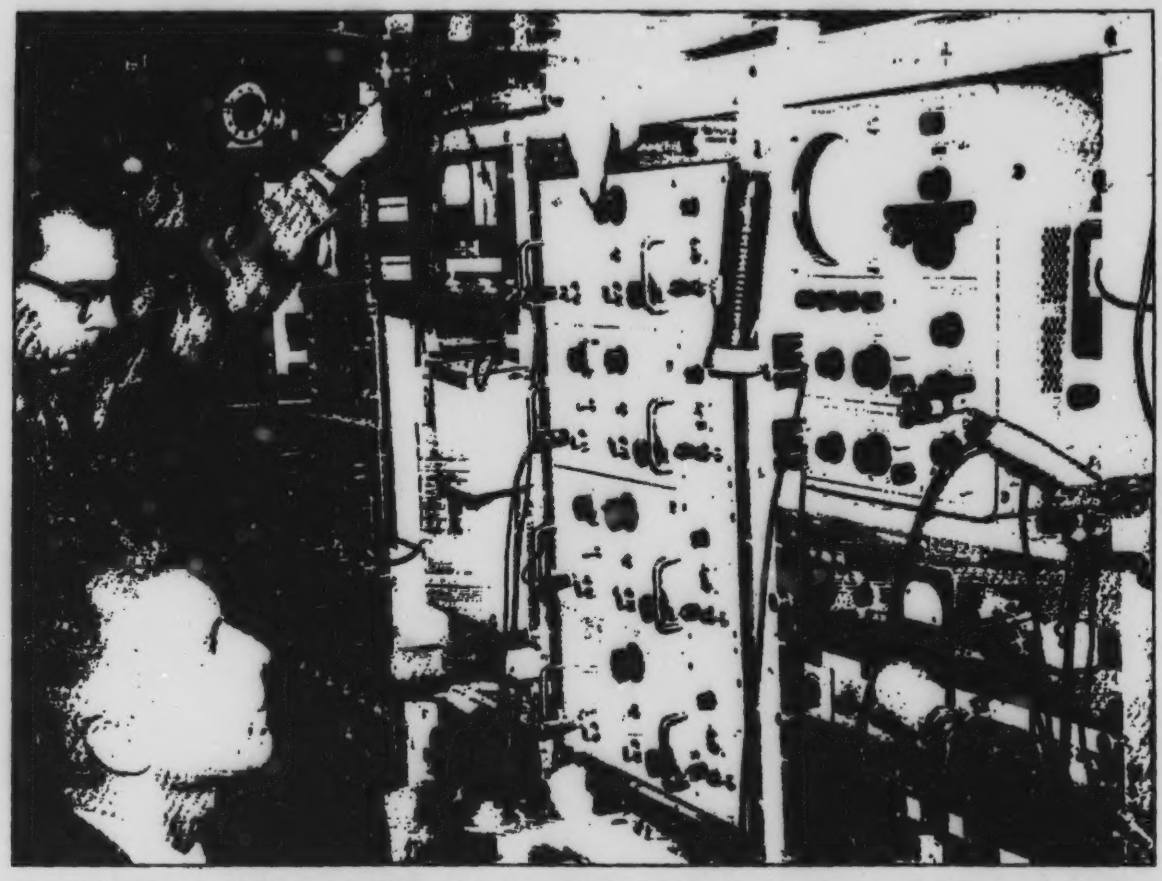
Making turbulent wakes

For the February 1960 cruise we had equipped the OSHAWA with a probe mounting on the bow of the ship so that we could sample depths close to the surface that could not be observed with the paravane-mounted probes at the stern. The main purpose of this was to attempt to measure the characteristics of wake turbulence by crossing our own wake or that of other ships. It turned out that our own wake was not a good subject for study because it took us so long to get around to it that we lost track of the detailed navigation. To use other ships we used to lie close to their projected track as the ship approached and then try to pass close under their stern without spooking the unsuspecting watchkeeping officer into some violent evasive maneuver. Even when we told them that we were going to pass close aboard it created a good deal of unease. On the whole this procedure turned out to be unsatisfactory because, although we could observe the wake close in, we were working in the near surface region where the wind waves caused quite high turbulence levels which were high noise levels where wakes were concerned.

It was probably in the summer of 1960 that we decided to try to get around this near surface noise problem by making our own deep wake. Oceanographers at Woods Hole had discovered that old parachutes made good drogues for drift poles so we reasoned that if we could tow one at depth it would put lots of turbulence in the water behind it. We discovered that the drogue parachutes used to decelerate fighter aircraft when landing were discarded after a dozen or so deployments and Tony negotiated a free supply of used chutes from CFB COMOX despite a regulation that required them to be destroyed so no idiot could try jumping out of an aircraft with one.

The word idiot was never far from the minds of CNAV crews, most of whom had had experience with scientists on research ships, but when we arrived on CNAV HEATHERTON with a bundle of cloth and told them that we wanted it towed at the end of a one inch diameter steel tow line they thought the case was proven. The first few trials didn't make us look any better because the parachutes towed in a unstable mode in which they described circles of ever increasing diameter in a plane normal to the tow line and when one edge broke the surface of the water the uneven load would cause them to disintegrate spectacularly. We tried several schemes to make the things stay down and the most successful was to put half a ton of anchor chain on the end of the tow wire. With that weight we managed several times, over a period of a couple of months, to work the big tug up to her full power of 1,000 hp and a speed of only one or two knots, but even with this weight the parachute always managed to break surface within a few minutes and reduce itself to shreds. Everybody had to be impressed with the fantastic towbar pull that we could apply to our little piece of cloth but unfortunately we did not find a way around the towing instability. Not long after this the Navy acquired the submarine HMCS GRILSE, an old USN Fleet boat, and before they knew what they were going to use it for we had booked some time to start looking at a real submarine wake.

At sea in a submarine



Harold Grant and Tony Moilliet with four racks of electronics jammed into a submarine

The observations in Discovery Passage were made in extremely intense turbulence where the turbulence signal was well above the noise level of the instrument over most of the spectral band. In more normal parts of the ocean the turbulence is much less energetic and the fluctuating velocity signal is much lower. The hot film probe, like most velocity sensors, measured the relative velocity of the water with respect to the probe. Any oscillating motion of the probe itself induced a spurious signal which could be a serious source of background noise. It is not easy to tow a sensor through the water at a steady velocity. Vibrations due to eddy shedding around the towed body or the tow cable or motions forced by wave action are usually in the frequency range of the turbulence signal and can mask the signal entirely. In 1961 and 1962 a hot film probe and some high frequency temperature sensors were mounted on a mechanism that allowed them to be extended out of a forward torpedo tube in the submarine HMCS GRILSE. The large mass and size of the submarine prevented most effects of vibration and wave action and it was possible to make the first measurements of turbulence in the open sea.

Operating in a submarine was a new experience for the Fluid Dynamics Group. Four Hammond racks of electronics had to be taken down the main hatch in pieces and assembled in the forward torpedo room. On the first trip the Ampex tape recorder deck had to be stripped down to less than the bare essentials to get it through the hatch. A Precision recorder that would go through the hatch intact was obtained for later cruises. Graeme Dennison designed probe holders mounted on a long aluminum tube that was supported by a steel frame inside a forward torpedo tube and could be extended through the open muzzle door to several feet beyond the bow of the submarine. This contraption was operated by a crank in the torpedo room. It was a simple matter to extend the instruments at the beginning of the dive but at the end after 12 or 13 hours, cranking was exhausting work in the environment of depleted oxygen.

In addition to long dives, the old submarine was being pushed to the limits in other ways. For example it was not designed to fire torpedoes below 200 feet and Graeme was concerned about the strength of the breech door at 300 feet. He designed a steel strongback to brace the door but it was heavy and inconvenient so it didn't always get used. After the first cruise he took the breech door to Don Tweedhope for nondestructive evaluation. After X-raying the door Tweedy reported that it was a very porous casting and of doubtful strength. After that we got a new door that Tweedy approved of and all concerned had a new appreciation of the value of the strongback.

HMCS GRILSE - loading the frame which supported the probe carrier inside the torpedo tube

Observations were made in moderately rough seas and it was found that at all depths down to our maximum of 300 ft the dominant fluctuating velocities were the orbital motions of the surface waves. Above the thermocline the water was everywhere turbulent as might be expected under these conditions. In the thermocline, there were patches of turbulence even where the mean density gradient indicated a very stable structure. Some patches had horizontal dimensions of hundreds of metres but the vertical scale was apparently of the order of one metre. This observation was one of the very first to uncover some of the complexity of the thermohaline and velocity fields in the thermocline. This has been the subject of a great deal of research by many laboratories over the past thirty years and much remains to be understood.

In the course of investigating turbulence patches it was necessary to distinguish them from turbulence generated by the submarine. To accomplish this, on the third cruise, the wake of the submarine was dyed with Rhodamine-B, a strong red dye that could be detected in minute quantities by a fluorometer. The dye was pumped from a rubber bladder on the deck by a pump on the radar mast through an outlet at the stern. The pump was operated by an automobile fan blade on the mast and was started and stopped by turning the radar antenna which would interfere with the blade rotation. (On one occasion, when the pump failed and was dripping a concentrated solution of Rhodamine-B, Bill Vogel, who joined the group in 1962, volunteered to climb the mast and remained red for several days.)

It turned out to be easy to identify the wake turbulence when it was dyed in this way and we were able to follow wakes for a considerable time, but without the dye there was no obvious way to distinguish wake turbulence from the patches of turbulence that occurred naturally in the thermocline.

Towing instruments in the deep sea

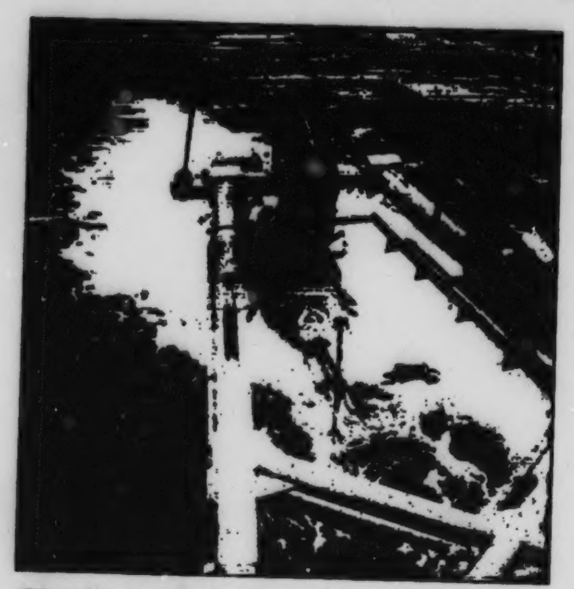
Because of the depth limitations of the only available submarine, we could not explore the important depth range below 300 ft which was available to modern submarines. In many ocean areas the limiting depth of GRILSE corresponded roughly with the bottom of the thermocline so there was no justification for extrapolating the knowledge that we had gained in the thermocline to greater depths. We decided to develop a measurement system using a large streamlined body towed below a surface ship. The paravane that we had used in the inside waters would not work at sea because it pitched violently if the stern of the OSHAWA was heaving, and the drag of the bundled tow cable was too high to permit towing below 300 ft.

John Smith who had just joined the Electrical and Mechanical Engineering Section was assigned to deal with the mechanical aspects of this task. The Naval Research Establishment in Halifax had been involved for some time in the development of variable depth sonar and they provided the CANBY, one of their early towed bodies which John proceeded to adapt for the new system. (The name CANBY didn't stick. The crew soon named it "Overtime Charlie" and "Charlie" it remained.) We also obtained much of the towing gear which had been used on HMCS CRUSADER in Nova Scotia for the early VDS trials. The towing winch was an old steam minesweeping winch purchased from a local scrap dealer for 10 cents/lb (it was rumored that they had bought it from the Navy a few months before for 3 cents/lb!) that we converted to hydraulic power with electronic controls. Since the OSHAWA was a former ALGERINE class minesweeper the winch fitted in place of her regular steam winch. Bob Chappell built the electronics and John originally specified that the body depth be controlled by a feedback circuit

A Controlled Leak

The fluorometer required a continuous sample of the ambient sea water which was provided by a controlled leak which was discharged into the bilge after passing through the fluorometer. Water was sampled through 1/8 inch diameter soft plastic (Tygon) tubing which was open to the sea at one end, a few inches from the velocity and temperature probes, and passed through a gland at the breech door of the torpedo tube. The total length of plastic tubing was about forty feet and the excess was coiled up inside the torpedo tube. The rate of flow was controlled by the Bernoulli effect. An increase in the flow rate caused a drop in pressure in the tube, reducing the cross-section of the tube and the flow rate. This was a stable feedback system and the flow rate was constant within 10% for a depth range of 50 ft to 300 ft. The actual flow rate depended only on the length of the Tygon tube which was determined empirically by experiments in one of the Heavy Lab pressure tanks.

from the depth gauge. That is where it became evident that sloppy gears, which were satisfactory in an old steam winch, deliver phase shifts in a modern control circuit. A twelve ton winch in oscillation is an awesome sight—with the sound effects to go with it. The final control circuit included feedback from the depth gauge signal with a very long time constant, while short-term depth-keeping depended on a signal from an accelerometer on the stern of the ship without feedback. The body could be towed at a constant depth or in a cycling mode where the depth followed a sawtooth pattern. In either case the depth could be maintained to within a metre when the stern of the ship was heaving eight metres. The 1,200 ft of 1.125"diameter tow cable was the NRE 2Q design and we reduced the vibration problems by using 300 ft of VDS fairing on the bottom portion. There were 21 electrical conductors and the winch had a special spooling arrangement for the deck lead so that slip rings were avoided completely. All this gear was originally mounted on the OSHAWA but it was soon transferred to the ENDEAVOUR where, during construction, the hydraulic pump for the winch was installed permanently below decks and appropriate stiffening was provided on the quarter deck and transom.



Charlie secure in the saddle of the towing arm but still crashing in and out of the waves

Grabbing Charlie In Rough Weather

Getting Charlie to tow smoothly in rough weather was a big problem which was largely solved by applying good engineering principles. Grabbing him as he approached the ship with his delicate instruments was a skill that had to be learned. The first thing was to turn the ship so as to run before the sea. This way the big waves, which were traveling much faster than the ship, were approaching us from the stern and the wave encounter frequency was minimized. The towing arm was lowered until it was just below the surface. We would haul Charlie up to within about 30 ft of the surface where we could see him. At this point, if the sea was causing the ship to yaw it was something like having a huge fish sheering around on a line. John Smith had the winch control in his hand and we stood at the end of the deck watching the sea for about seven waves back. When we saw a few low waves coming the irreversible decision to recover was made and John began to haul in the wire at maximum speed. During the thirty seconds or so that it took to grab Charlie in the saddle of the towing arm our wave forecast was rapidly deteriorating and we had some pretty good crashes but never a disaster.

This towed body eventually carried a conductivity sensor, designed by Bob Chappell, and three fast response thermistors in addition to the main velocity and temperature probes. Probe vibrations remained a problem with the velocity measurements but with careful shock mounting valid results were eventually obtained. This work, largely reported in P.W. Nasmyth's PhD thesis, demonstrated that turbulent patches existed down to at least 1,000 ft, well below the main thermocline, although at these depths only about 5% of the water was turbulent. A great wealth of information was discovered about the fine structure including many unexpected features.

It became apparent at this point that it would be very difficult to distinguish a submarine wake from these patches of turbulence and that a robust sensor suitable for operational use was not in sight. Over a two year period, starting in 1970, this project with its unique equipment was turned over to the Institute of Ocean Sciences of the Department of Fisheries and Oceans where important studies on small scale structure of the ocean have been pursued to this day.

Internal Waves

General

It had been known for 60 years that, under appropriate oceanographic conditions, ships and submarines could generate internal waves. These are gravity waves that propagate on density gradients below the surface of the water and which constitute another class of small scale motions that are found in the ocean. There are of course other sources of internal waves in the ocean and most of these derive their energy either directly or indirectly from the tides. Like the turbulence discussed above, these waves are mostly hidden from view and in 1964 there was very little practical knowledge about them. In addition to this there was no advanced theoretical knowledge of the generation of internal waves or the interaction between them and the wind waves on the surface above. At this point Blyth Hughes rejoined the group after completing his PhD and he contributed his skill in theoretical physics and made a major contribution in the design and conduct of experiments.

Because of the prevalence of low salinity surface water and strong tidal flows, the Strait of Georgia and some of the mainland inlets have some very energetic internal waves, first described by Art Shand in research he did in 1950 before joining PNL. Once again these sheltered waters provided DREP with unique opportunities to study an ocean phenomenon in a setting where delicate instruments could be used without the complications and risk of damage associated with high sea states. Internal waves in Georgia Strait are mostly generated in the tidal passes around the Strait and are often visible from the air because they modify the surface waves and create large visible patterns especially under light wind conditions. In Bute and Knight Inlets the surface water can be nearly fresh at times of high river flow. The water structure below the fresh layer includes a very large density gradient, and on this gradient internal waves are induced by tidal flow over the sills near the mouths of the inlets. Ships and barges in the area can also interact with the density layers to generate internal waves.

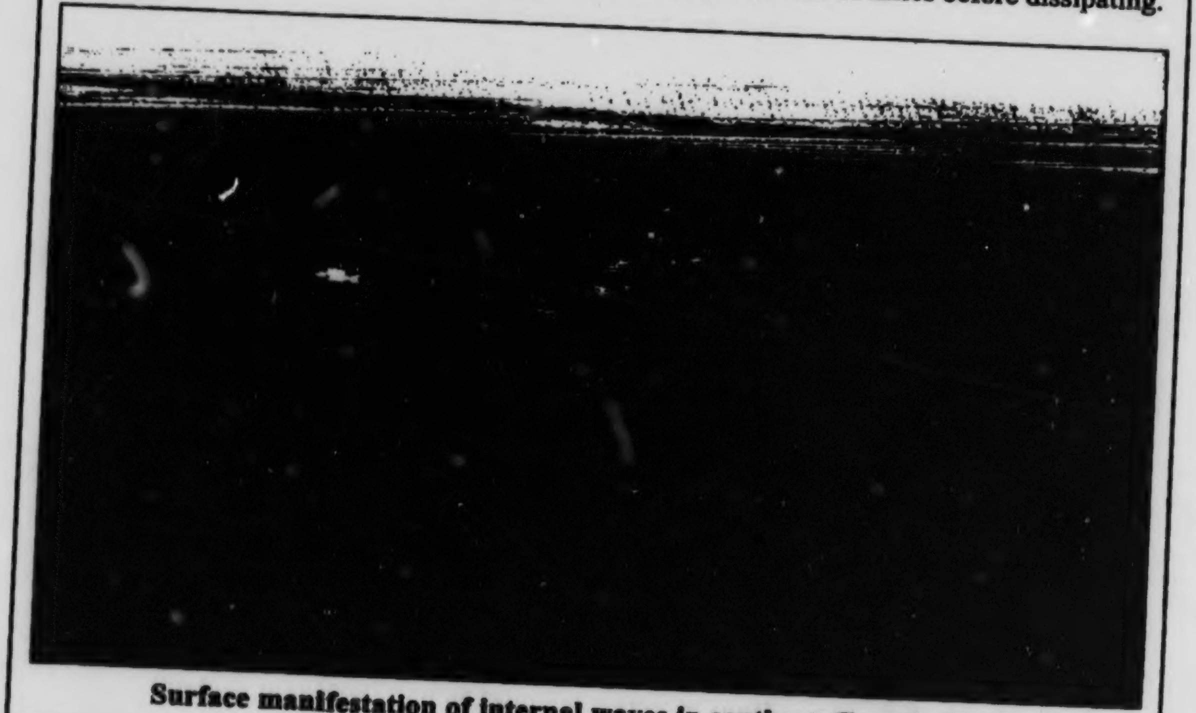
Instruments for Georgia Strait and the inlets

For initial studies of internal waves it was decided to use the surface effects visible from the air to pick regular wave patterns that might be characterized by relatively simple and straight-forward measurements. The visible effects on the surface of the water seemed to be best characterized by the statistics of the surface wave slope which would depend on the modification of the surface waves by internal waves. It seemed possible that a fairly detailed description of the internal waves could be inferred from observations of the surface effects, so surface slope was an important parameter to measure. To describe the sub-surface motion we could look at the temperature structure of the water column to illustrate the vertical displacement of the water or we could measure the horizontal velocity of the water which is closely related to the effects on the wind waves.

Again we found that there were no instruments available to measure any of these quantities on the spatial scale and frequency range that we expected to encounter. This situation led to the development of complex instruments to measure the surface slope, isotherm displacement and water velocity, associated with internal waves. To maintain a qualitative understanding of the overall picture, aerial observation was essential and there was a helicopter-borne camera for recording surface effects. Camera angles were automatically determined with respect to an airborne gyro compass and transmitted with aircraft flight parameters to the ship for recording. The recording system handled 38 channels of data at a variety of sample rates. None of these instruments was intended for use in the open sea but it was assumed that much could be learned about internal waves in the low sea states of Georgia Strait and the mainland inlets.

The Internal Waves of Georgia Strait

Almost none of the ferry passengers who enjoy a quiet crossing of the Strait of Georgia on a calm summer day are aware of the huge waves passing beneath their feet. The waves that create the visible effects in the accompanying picture are at least twenty feet high although only water well below the surface is actually moving up and down that much. It is the nature of these waves that they cause the surface water to move back and forth horizontally and it is this divergence and convergence of the surface water that flattens or amplifies small surface waves to produce the visible patterns. The distance between internal wave crests is typically 400 ft and the waves travel at a speed of about 1 knot which is very much slower than the speed of surface waves of that wavelength. These waves are generated in the tidal passes such as Boundary Pass and often travel for tens of miles before dissipating.



Surface manifestation of internal waves in southern Georgia Strait

The wave slope meter

It was evident that the most prominent surface manifestations of the internal waves of Georgia strait were due to modification of the statistics of the slope of the water surface which in turn led to the reflection of different parts of the sky from different areas of the wave field. Even on a clear day the brightness of the sky is not at all uniform with the sun being a very bright spot and other areas having considerable gradations in brightness. The result is that relatively rough or smooth bands are seen with striking contrast but not much change in colour. (There are prominent coloured effects in Georgia Strait as well and these are often seen from

Turning a Research Vessel Into an Aircraft Carrier

ENDEAVOUR was provided with a helicopter deck and hanger in the original design with the idea of providing a capability of navigating through leads in arctic ice. When we developed a very similar requirement, navigating among large internal waves that could only be recognized from the air, the only problem seemed to be that we didn't have a helicopter. We contacted the Coast Guard which operated helicopters from small ships and they kindly agreed to lend us a small Bell G2 for a couple of days to see how it worked. The first indication that life was not as simple as it seemed was when the pilot refused to use gasoline from ENDEAVOUR's aircraft fuel tank which, like all the other fuel tanks in the ship was water compensated. i.e. as fuel was used it was displaced by sea water from below. The captain, on the other hand would not have barrels of fuel on deck unless they were in racks from which they could be jettisoned immediately in case of fire. I think we settled for a very small number of barrels in a useful position on deck.

We were proud of the fact that we had not only a helicopter deck but a hanger as well. On the first day, however, after making a couple of take-offs and landings the pilot and mechanic moved their helicopter into the hanger and immediately declared "Never again!". There was not enough room to work around this smallest of helicopters and they were afraid that if the ship rolled the blade would strike the ship's structure and would be damaged. From that time on, the principal use of the hanger was as a putting green for the Chief Engineer. (He had a nice green indoor-outdoor carpet.)

We used Coast Guard helicopters several times after that and their pilots were very helpful and patient with greenhorns who had to learn what they could and couldn't do with helicopters. We soon found, however, that the Coast Guard could not provide the time we needed because their regular work had priority. Fortunately charter helicopters were available from a number of local companies.

Very early in the game NDHQ discovered that we were flying helicopters from the ship and that the Department had no regulations for such an activity on civilian ships. DND abhors a lack of regulations and new rules began pouring in on us. For a time they banned all flying but after a lengthy investigation a new book of rules was created and a fire party was given special training in fighting aircraft fires. Every take-off and landing required that the fire party be assembled and dressed and that all other personnel leave the upper decks. This eventually settled down to a regular routine but an unauthorized landing occurred one day when the ship was anchored in Bute Inlet and a strange helicopter dropped down on the deck without warning causing great consternation. It turned out that the pilot was simply asking directions to our collaborators, the crew of the USS X-1, who had ordered him to come from Campbell River with all the beer he could lift.

the air when looking down at steep angles. These effects, which we called "green tubes" although they are often brown or red, appear to come from below the surface and are probably due to the concentration of plankton or silt on certain phases of the internal waves. This phenomenon is thought to be dependent on the peculiar nature of the Strait as an extended estuary of the Fraser River and not as general as the interaction of internal waves with wind waves.) In order to make an experimental investigation of the interaction of the internal waves with the surface waves we had to devise a way of measuring the slope of the water surface.

The wave slope meter was a large optical device which measured the slope of the water surface by using the refraction of a laser beam passing through the surface. It was designed to be suspended from a crane, 10 m ahead of the bow of a research vessel, and to accommodate wave heights up to about 0.8 m. The principle on which the instrument was based had been suggested to us many years before by Bob Stewart but until the advent of lasers, vidicons and digital electronics it had not been practical. In 1966 when we set out to develop the equipment, suitable lasers had become available but the vidicons were less than adequate and no one at the laboratory had attempted real time digital signal processing of the type required.

The Fluid Dynamics Group 1972
Back - Tony Mollliet, Harold Grant, John Smith, Blyth Hughes
Front - Bob Chappell, Dick Anderson
Inset - Tony Pastro, who took the picture above

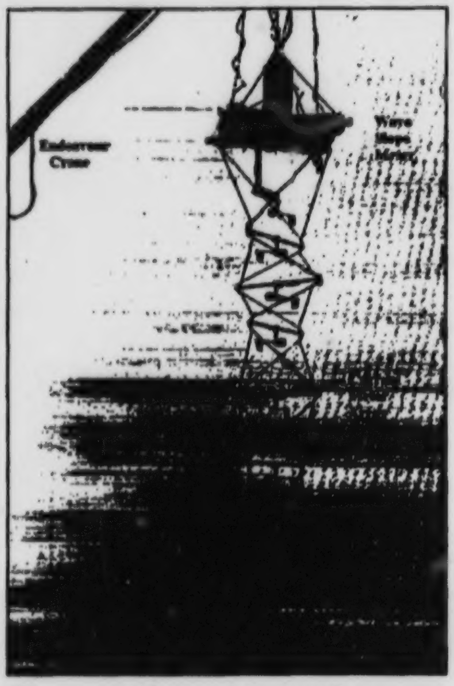
From a laser held below the water surface, a very narrow beam was directed vertically upward through the water surface and, after refraction, it passed through a large lens and fell on a translucent screen placed at the focal plane of the lens. To the first order, the location of the spot on the screen depended only on the slope of the water surface and, in particular, not on the water height. The first limitation to the design was the availability of a suitable lens wide enough to collect light from large slopes but still allow the wind waves to pass under it. We soon discovered that the largest lens blanks of optical glass normally made were 12 inches in diameter, and that there was only one such blank in Canada at the time. Even a simple lens of this size would take three months to grind so we gave up thoughts of a compound lens with low spherical aberration and went for a simple lens. The screen was viewed by a heavily modified television camera and fast (for the time!) digital circuitry was used to determine the x and y coordinates of the spot in each frame. Subsequent processing of these numbers made corrections for lens aberrations and provided the two components of slope as time series. Slope was determined at the rate of 112 observations per second averaged over a spot only about one mm in diameter.

The current meter array

It was clear from observing the surface of the water that the water currents in some of the internal waves were substantial but there was every reason to suppose that some very small variations in currents could be significant. The region of interest was very near the surface where water motion in the wind waves could also be large. To complicate matters further, the presence of a large steel ship made the use of magnetic compasses impractical for measuring current direction. The solution was to tow a vertical array of seven current meters hung directly below the wave slope meter, 10 m ahead of the bow of the ship.

The current sensors were specially constructed impellers with electrical output signals provided by optical choppers. The sensor heads were mounted on vanes which were free to rotate about a vertical axis and thus free to point the sensors into the flow. The array was supported on a structure of pipes and wires that was designed to be rigid with respect to torque about a vertical axis. The orientation of the structure could thus be determined with the ship's gyro compass and the directions of the current meter vanes were measured with respect to it with resolvers, thus avoiding the use of magnetic compasses.

This rather unwieldy structure could be managed in the low sea states of the inside waters and since it was towed at a mean speed slightly faster than the maximum currents in the internal waves, the water speed with respect to the meters never fell below the starting threshold of the impellers and the relative direction of the resultant flow varied by only a modest amount.



The wave slope meter and current meter array suspended in the air

The seven current meters can be seen in the accompanying photograph. When the array is lowered into the water, the top meter (which is attached to the laser case) is at a depth of 1 m and the bottom meter is at 10 m. The water level is halfway between the laser case and the large lens which is in the centre of the fabric sunshade which appears black in the photograph. The translucent screen and the vidicon are in the box at the top.

The Yo-Yo

Another unique instrument developed for this study was the "Yo-Yo." Its purpose was to provide a contour plot of temperature vs depth and horizontal distance in the internal wave field. This had traditionally been done with thermistor chains but for the detail required in the Georgia Strait waves this would have required a chain of many closely spaced individually calibrated thermistors to provide a resolution of a few centimeters over a depth of 30 m, and more computing power than we had in those days. The solution was to use three tiny rapid response thermistors, spaced 10 m apart on a vertical 'clothesline,' which rapidly cycled up and down over a 10 m range using an automatic reversing winch. The bottom of the 'clothesline' was held down by a large weight suspended on a sheave so that the winch did not have to accelerate the weight.

This was a pretty wild machine driven by a standard oceanographic winch running at maximum speed and reversing about every ten seconds. Although it was very simple in principle, it was difficult to implement in practice because of the high acceleration required of the thermistor carriers and because of metal fatigue in the electrical wires which were continuous to avoid the use of slip rings. Most of the design was done by John Smith and Bob Chappell but Graeme Dennison took the difficult job of taming the flying electrical cables. Reliable results were obtained about 1968 and included very detailed plots of isotherm displacement in the internal wave fields. Blyth Hughes was able to show that particle velocities calculated from the measured isotherms in the waves were equivalent to those measured with the current meter array. This result verified the applicability of existing theory to these waves and allowed us to dispense with the Yo-Yo in later trials.

The helicopter-borne camera

In attempting to understand the internal wave patterns, and to measure them for comparison with theoretical models, it became apparent that some kind of plan-view pictures of the waves would be of enormous value. Blyth Hughes was the DREP researcher with the job of being flown around in the helicopter (which for these experiments was carried on CFAV ENDEAVOUR). His main task was to spot the "good" internal wave sets—or to determine when "good" sets had been produced—and to direct the ship with its measurement apparatus into the

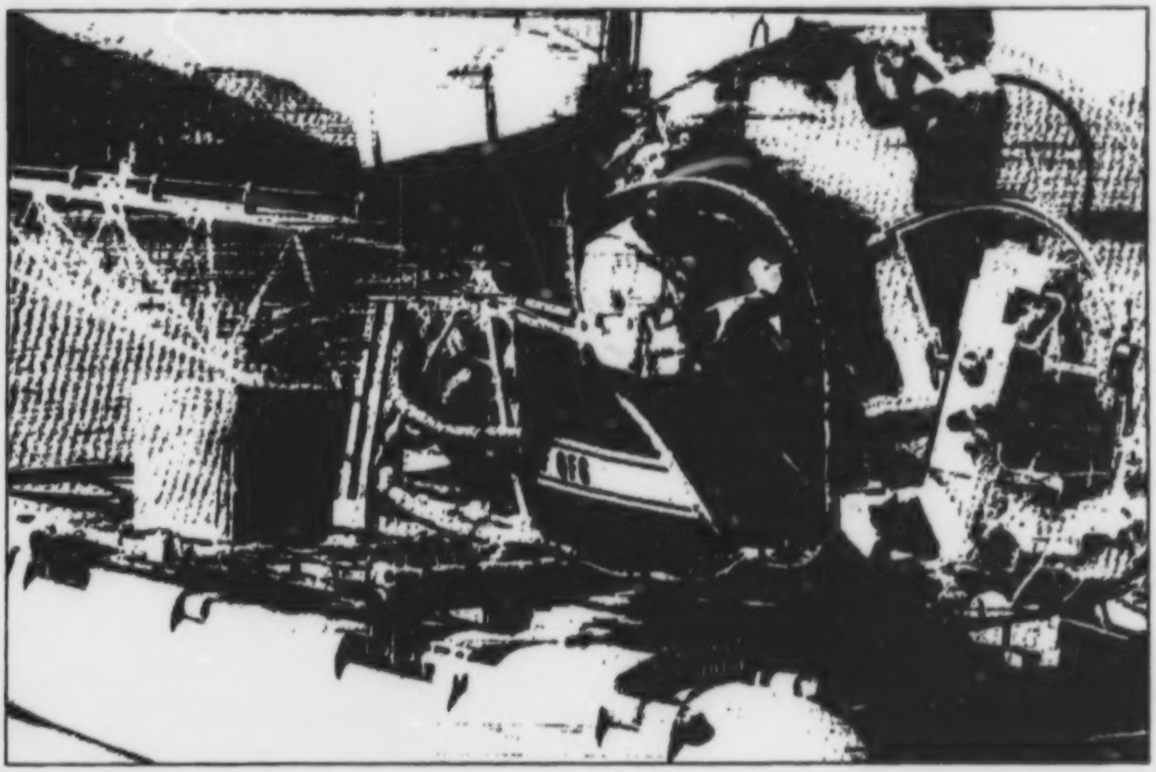
These internal waves were generated by the ENDEAVOUR moving slowly astern in Knight Inlet. The picture shows the ship proceeding ahead to measure the properties of the wave field.

wave fields in some direction that would lead to an appropriately simple analysis later on. He also took photographs of the ship and wave fields to provide supporting evidence for later reconstruction of what the ship-board measurements meant. Harold Grant devised computer programs to convert oblique photographs to horizontal "maps" of the surface but the process of determining the camera angles was time consuming and required that three points of land be identified and accurately located in the photograph—a condition that was not met in every photograph.

To overcome this difficulty a small aircraft gyrocompass was obtained and fitted onto one of the helicopter pontoons along with a rate gyro that provided a vertical reference. John Smith then designed a jointed strut with syncros that related the gyro measurement to the camera body, but allowed for wide flexibility in the camera's orientation. Bob Chappell modified the camera so that the shutter release activated a digital acquisition of all the relevant angles, from camera orientation with respect to the strut, to the orientation of the gyro mechanism itself, and he constructed a radio-telemetry link to relay this data as well as the aircraft altitude to the ENDEAVOUR each time a photograph was taken.

There were many different parts to the jointed strut, and each had to be measured very accurately to determine camera angles relative to the gyro. In addition, the gyro had to be calibrated before and after each flight to make sure it hadn't "wandered" too far from its own baseline orientation. This was done by having Blyth sight the camera along a line drawn on the helicopter deck parallel to ship's head (an orientation that was known from the ship's master gyro) and activate the telemetry readout system.

When it all worked, this system was a good one. When it didn't—and for part of its



The instrumented helicopter on deck

"life" the gyro had an internal intermittent fault that was very frustrating to locate—it was an exercise in experimental discipline and dogged persistence, i.e., in continuing with its use while searching for errors.

Assessment of internal wave fields

By 1968 all this instrumentation, including the aerial camera, had come together as a unified structure with a single recording system. The Naval Research Laboratory (NRL) had been studying similar oceanographic problems with different but complementary instruments and in 1969 a joint experiment was arranged to take advantage of the special water conditions of Bute Inlet and Georgia Strait. NRL provided the 50-ft research submarine USS X-1 and a chartered aircraft while DREP supplied CFAV ENDEAVOUR with a chartered helicopter on board, and a barge with living quarters for the crew of the X-1. Since sonar would have been useless for tracking the submarine in the high reverberation between the vertical rock walls of Bute Inlet, DREP supplied a 21 foot long tethered balloon which was attached to the X-1 and was tracked by ENDEAVOUR's radar.

Harold Grant was chief scientist, assisted by Dr Joe Elliot of NRL and they directed the movement of ships and aircraft from the ENDEAVOUR. Blyth Hughes was the DREP airborne observer and manned the helicopter camera. Other DREP personnel included John Smith, Tony Moilliet, Bob Chappell, Dick Anderson, Tony Pastro and Roy Gravells. The projects at DREP and NRL were very closely integrated and the study produced valuable results.

In the summer of 1972 an extensive experiment was conducted in Knight Inlet and Georgia Strait. It was found that internal wave fields could be reliably generated with the ship so it was no longer necessary to rely on the tidally generated waves. By proceeding astern at speeds between one and two knots the ship induced internal waves in the shallow pycnocline and detailed observations of them were made with most of the instruments described above and some others. Lengthy analysis of this data led to published results relating parameters of the surface wave slope to the characteristics of the internal waves below. This study also confirmed an important relation between mean square surface slope and wind speed that had been obtained by Cox & Munk using a completely independent method under very different atmospheric and oceanic conditions.

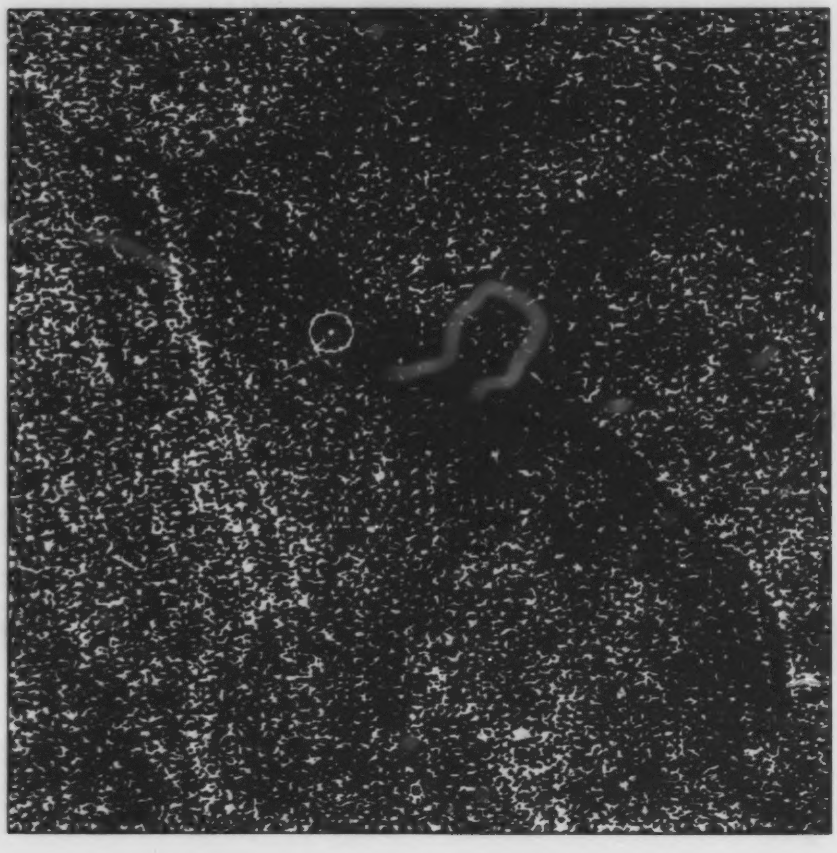
In 1973 Harold Grant was appointed director of the Physics Division and Blyth Hughes became Leader of the Fluid Dynamics Group.

Remote Sensing

SEASAT

During the early-to-mid 70s the DREP program was oriented mainly towards research into the use of surface expressions of internal waves as indicators of the presence of submerged submarines. The previously mentioned relationship between surface-wave modulation and internal-wave horizontal surface current that was found (both experimentally and theoretically) was a major step forward in this program, but there still was no efficient way of monitoring relevant areas of the world's oceans—or even more localized coastal portions, or suspected transitting lanes—for identifiable patterns in the surface wind wave fields.

That situation changed completely in the summer of 1978 when NASA launched SEASAT, an orbiting satellite dedicated to remote oceanic measurements. SEASAT specifically included a Synthetic Aperture Radar (SAR) for backscatter measurements of ocean waves, and it was recognized that satellite-borne SAR was a potential wave monitoring system that could make the global surveillance problem feasible non-acoustically. But very little was actually known about the physics of backscattering processes, or about associated noise levels and detection capabilities. In July 1978, we decided to make use of this new device, but it meant "chasing" SEASAT's orbit along the inside waters between Vancouver Island and the British Columbia mainland, from Queen Charlotte Sound in the North to Boundary Pass in the South. The satellite had been launched in June and its orbit had not been stabilized by the NASA control people so we had to continuously alter the experimental locale to fit the SEASAT SAR coverage. With additional remote coverage using SAR equipment mounted in a Convair 580 (operated by the Canadian Centre for Remote Sensing), we were able to obtain simultaneous imagery of striking natural internal wave sets in Southern Georgia Strait and to compare this imagery with surface truth measurements consisting of surface currents, wave slope statistics, and wind data. The illustration on this page shows a SEASAT SAR image of a portion of Georgia Strait including the research ship CFAV ENDEAVOUR and surface wave patterns partly caused by internal waves. This is one of the first radar images of internal waves taken from space.



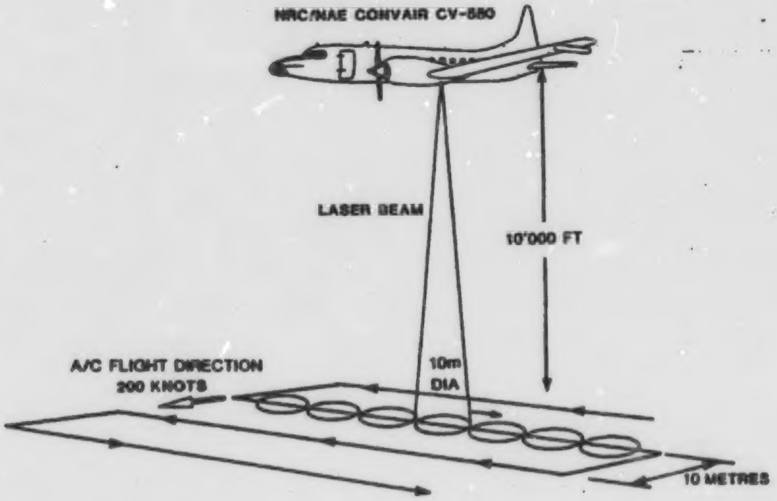
SEASAT SAR image of Georgia strait. The ENDEAVOUR is in the circle and the linear patterns particularly at the lower right are internal waves. Each edge of the image is 5 km long.

Blyth Hughes, Tony Moilliet, Bob Chappell, Tony Pastro, and John Blommers were the DREP personnel on CFAV ENDEAVOUR, and strong support for the planning and analysis of this experiment was contributed by Jim Gower of the Institute of Ocean Sciences (Sidney, BC).

Comparisons between the data sets showed that correlations did indeed exist, but that the data were not capable of providing the details necessary to complete useful models of the backscatter process.

Ocean Surface Roughness Measurement System (OSRMS)

Some theoretical calculations done by Blyth Hughes indicated that a nadir-looking scatterometer might have a signal-to-noise advantage in detecting roughness variations in the ocean's surface, and so we considered this as a possible special DREP area of research. SAR was burgeoning as an ocean monitor, and US and other Canadian agencies were already exploring its potential. As well, SAR systems were very expensive devices to build, operate, and do the processing for, and so the DREP decision was to pursue a complementary parallel (and simpler) approach using the nadir-scatterometer. Proposals were called for and a contract was subsequently let with SPAR AEROSPACE of Toronto, to build such a device centred around an infra-red laser as the operative source for the backscattering beam. It was completed in the early 80s in time to be incorporated in a major joint experiment with the US. The beam itself was essentially vertically-directed but it was scanned through a small range of angles from side-to-side perpendicular to the aircraft track and so it mapped out a swath on the ocean surface as the aircraft flew along. Collection optics were simultaneously oriented (and scanned) downwards, parallel to the beam, to receive the backscattered infra-red energy. The proportionate amount of energy backscattered is controlled by the roughness of the surface at the scattering location (a "spot" of about 10 m diameter), so maps of received energy are measures of maps of the surface roughness.



Configuration of Ocean Surface Roughness Measurement System

The device was mounted and flown in the Institute for Aerospace Research's Convair 580, which was made available to DREP. (IAR is part of NRC and was formerly called the National Aeronautical Establishment.) It required close alignment in its optical components and it was set up, operated, and faithfully overseen by Steven Hughes and Art Fitchett (and later, Laura Rempel). We had had it designed to fit very neatly in the "belly" of the aircraft, between and around the frames and struts which make up the aircraft's "skeleton," but it did not have much room left over for a person to get at the relevant adjusting screws for alignment. Prior to the early flights with this device, Steven got the job of "twisting" himself into this maze of equipment and aircraft parts to make these delicate adjustments, while Art or Blyth sat more comfortably and coolly outside assisting in the readouts.

We had already tested the concept by using a simpler, non-scanning "single-spot" device. This was built for us by OPTECH INC of Toronto, and we had flown it in a Britten-Norman Islander aircraft over Hecate Strait, Juan de Fuca Strait near Victoria, and Georgia Strait near Comox in regions that were also measured by the wave-slope meter and by meteorological equipment onboard CFAV ENDEAVOUR. Steven was the person in the aircraft for this work and he spent many hours, mostly upside down, looking at the equipment, making sure that it was working properly and generally managing the data acquisiton. Good statistics of the water surface were obtained and we were able to show that the "speckle" noise inherent in the backscatter process was commensurate with the best theoretical ideas of the day, and in fact, to be small enough to warrant continuing with the backscatter concept.

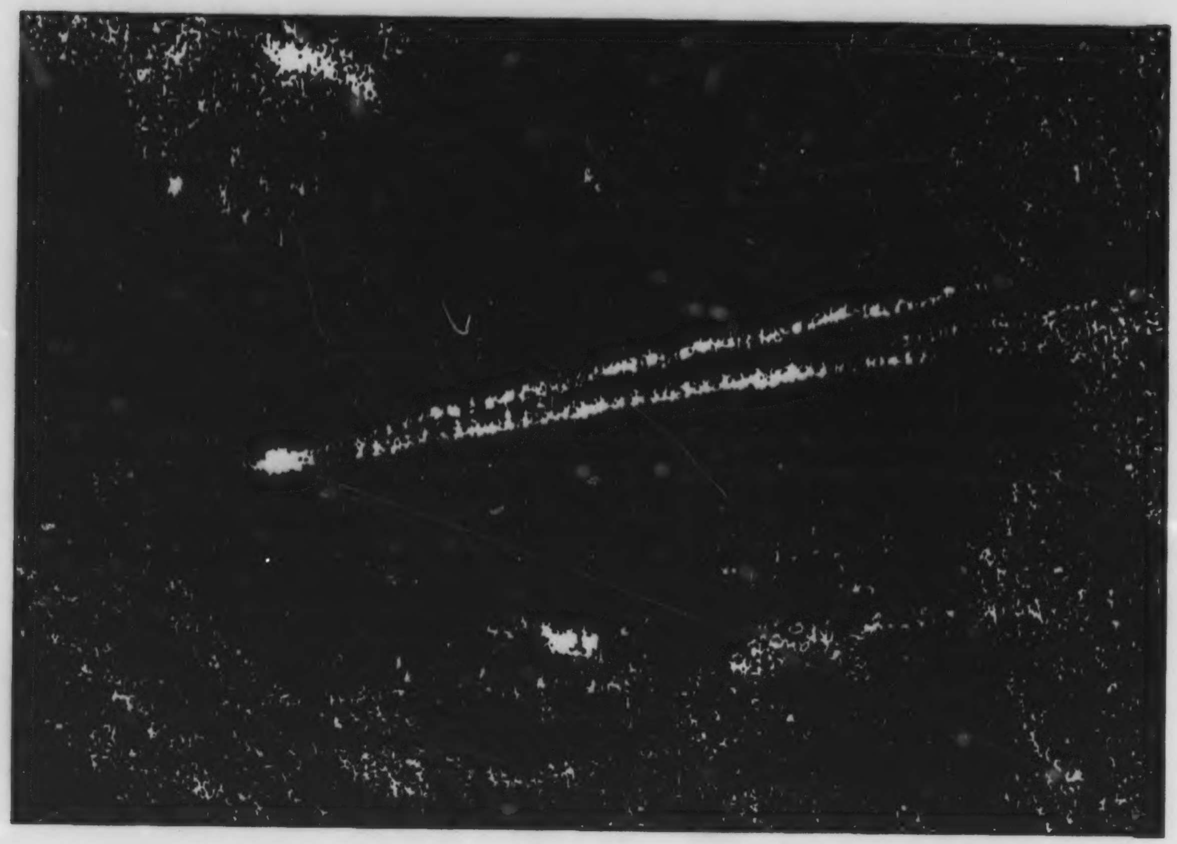
Working in the Middle of the Road

We had had some discouraging results during the first use of the single-spot device—we had designed a mount for it so it could be used on the Search and Rescue Labrador helicopters that are deployed from CFB COMOX, but their hovering capabilities were not stable enough to test the device properly, and every several seconds puffs of exhaust from the helicopter's engines would be blown into the optical path of the scatterometer leading to errors in the readings. To overcome some of this discouragement, and to really test the single-spot device, we wanted to put it on a "guaranteed" stable platform that had a clear "look" at a real sea-surface. We decided we could get all of these conditions by mounting the device on a frame overtop the central span of Lions' Gate Bridge (at the entrance to Vancouver Harbour). We also planned on having simultaneous coverage of the relevant oceanographic and meteorological variables by having CFAV ENDEAVOUR stem the tidal flow below. The process worked quite well technically—and for many hours Captain McMunagle of the ENDEAVOUR very gamely positioned the ship essentially in the middle of the shipping lanes into and out of this busy harbour—but the surface wave field in this region was affected too much by non-uniform local winds, and by wakes of passing ships and by currents, to give the kind of usefulness that was desired. (Eventually the Captain decided he'd had enough and the experiment was terminated!) It did reassure the DREP personnel (Steven Hughes, Trevor Dawson, and Blyth Hughes) that the single-spot device was indeed stable and provided clear backscatter measurements of the ocean surface. The experiment also provided some local newspaper coverage with a striking photograph appearing in one of the daily papers showing CFAV ENDEAVOUR under Lions' Gate Bridge.

John Wilson had designed the frame containing the bridge equipment and he had arranged to stop the traffic at about 4 a.m. one morning to allow a crane to hoist it onto the platform and install it properly—and the reverse when the experiment was finished. That part was smoothly operational and the equipment performed well, but two of the special conditions that remain in the memories of the operators on the bridge (Steven and Trevor) were the shuddering and shaking of the bridge when heavy traffic crossed over it, and the climb up to the housing over the deck of the bridge—this on a 20-ft ladder fastened onto the outside of the main bridgework with nothing but some 230 feet of air between the ladder and the water surface below, and with their guts saying "just climb, and whatever you do, don't look down!"

Joint Ocean Wave Investigation Project (JOWIP)

At about this time—in the late 70s and early 80s—considerable interest in non-acoustic submarine surveillance was being shown by DARPA and the USN, and funds became available in the US for some major experiments. With DREP's involvement such an experiment was planned for the coastal waters of British Columbia and Washington state for the summer of 1983. It was a very large undertaking for the DREP Fluid Dynamics Group, with two ships and five aircraft taking part with researchers from the Environmental Research Institute of Michigan (ERIM), the Naval Ocean Systems Center (NOSC, presently NRaD) of San Diego, TRW of Redondo Beach, CA, the Applied Physics Laboratory of Johns Hopkins University, the Canada Centre for Remote Sensing, and other contractors, as well as from DREP. Our objective was to determine, if possible, the modelling parameters and modelling comparisons for surface-ship generation of internal waves, SAR imagery of internal-wave-produced surface-wave patterns, scatterometer imagery of the same patterns, and details of the physics of the microwave backscatter process, and of the overall inherent noise levels.



SAR image of a surface-wave wake, taken in Dabob Bay, WA, from an aircraft. The white "arms" of the wake are ~1.75 km long. The "narrow-V" character is quite different from the usual photographic or visual images of surface-wave wakes. It also showed that more sophisticated wake/backscatter models were needed.

To accomplish all of this, a whole host of measurements were taken: SAR images, OSRMS images, microwave scatterometry, surface currents, surface wave slopes and heights, near-surface microwave backscatter ratios, oceanographic profiles, and wind data, along with the necessary tracking of all the relevant instruments and vessels.

From top to bottom and left to right: The NRC Convair 580; in the Convair, Art Fitchett (preparing), Laura Rempel (working), Steve Hughes (relaxing); on CFAV ENDEAVOUR, Trevor Dawson (not flying in the helicopter), Al Gillespie (enjoying a moment away from the computer).

The data were obtained in three different locales—Dabob Bay, WA, Southern Georgia Strait, BC, and Knight Inlet, BC. Art Fitchett, Trevor Dawson, Al Gillespie, Blyth Hughes, Steven Hughes, Tony Pastro, and Ray Tigg all took part from DREP with support from Bob Chappell. Blyth was the Chief Scientist, Trevor was the helicopter-borne observer and photographer, Tony did the photo processing, Al and Ray were in charge of the data-acquisition computers and of gathering the oceanographic samples, Art looked after the wave-slope meter and assisted Steven when he was operating the OSRMS on one of the Convairs. Steven had earlier greatly improved the electronic design of the wave-slope meter and John Wilson had improved its mechanical design. John had also designed much of the other mechanical equipment deployed from the ENDEAVOUR. After the experiment, Roy Gravells undertook the computer programming to synthesize and calibrate the data, and to process it into records that were more meaningful to the questions originally asked of the experiment. Walter Munk and Fred Zachariason from Scripps Institution of Oceanography and UCLA visited the Dabob Bay experimental site during one of the working days as guests on the ENDEAVOUR. They were both keenly interested in the problem of remote detection of ship-produced internal waves and were eager to witness the measurement process and its results first-hand. They were both very sensitive to the fact that this was not "their" experiment and they did not want to add to the organizational burden that accompanied the experiment—a sensitivity which underscores their stature in the field, and which also was greatly appreciated by the ENDEAVOUR personnel.

The results of the experiment were primarily contained in the clear correlations that were obtained between the relevant measurement sets, and in the confirmation that for natural internal waves the simple modelling of the measurement process was adequate to within factors of about 3 for longer SAR wavelengths. For shorter wave-length SAR the experiment showed that more complicated models were needed, and for ship-produced internal waves, the results showed that adequate models were still being awaited.

As part of another large consortium of research institutions, DREP participated in similar experiments on the US East Coast (off Long Island, NY) the next year, the SAR Internal Wave Signature Experiment (SARSEX), with more emphasis on the subsurface modelling of the natural internal waves that are ubiquitous there and are commonly seen in imagery obtained from spacecraft. These two major experiments, JOWIP and SARSEX, were reported in a special issue of the Journal of Geophysical Research in 1988. Steven Hughes and Art Fitchett were the primary researchers from DREP with some on-site participation from Blyth Hughes. The DREP equipment primarily centered around the OSRMS which was flown on the NAE Convair 580. The researchers stayed at Ronkonkoma, NY, and the aircraft were based nearby at Long Island's MacArthur Airport, with some overflight backscattering calibrations done at the Grumman Peconic River Airport.

Further work

Subsequent effort was devoted primarily to analyzing data from these major involvements, and to continuing the use of the OSRMS in natural wave situations off the west coast of Vancouver Island and in some work at CFMETR at Nanoose, BC. With this analysis, undertaken primarily by Steven Hughes and Trevor Dawson, we were able to show that the modelling could be trusted to within factors of 3 or 4 for long-wave SAR and for weak internal wave-surface wave modulations.

Simultaneous with this experimental and modelling work there was a significant effort to understand and properly model the inherent noise against which modulations would have to be detected. Blyth Hughes, Bob MacKinnon and Mike Wilmut (from Royal Roads Military College) were the ones doing most of this research.

Eventually enough of the pieces, from subsurface generation to remotely sensed imagery, were understood and modelled well enough so that we were able to make some general statements concerning the use of internal waves and remote detection as a surveillance method.

Arctic Modelling and Simulation

In 1987, we were reoriented as a research group, and were renamed. Some work in detection of wakes continued, but more and more of our effort was put into studies of acoustics in the Arctic, with emphases on Matched Field Processing, rough-boundary scattering, and maximum entropy analyses. Trevor Dawson and John Fawcett collaborated on a propagation program which allowed for arbitrarily-shaped (but 2D only) surface scattering, and Blyth Hughes investigated matched-field algorithms. Trevor and Blyth also continued to provide modelling for wake detection studies. Mike Wilmut pursued Hough transform implementations for detection algorithms, and Bob MacKinnon concentrated on maximum entropy formulations for image analysis. Programming support was provided by Don Berryman.

Statistical modelling of the roughness of the underside of the Arctic ice-cap was also undertaken, first by Bob MacKinnon and Mike Wilmut, and then by Blyth Hughes, ultimately showing that sequences of lognormal distributions fit the measured data very well. Good simulations of ice undersides were also routinely generated.

At his retirement party, Blyth Hughes - flanked by Tony Moilliet, Harold Grant and Mrs Hughes - demonstrates his flawless management technique, which never failed to bring out the best effort from his contractors

4. MATERIALS TECHNOLOGY

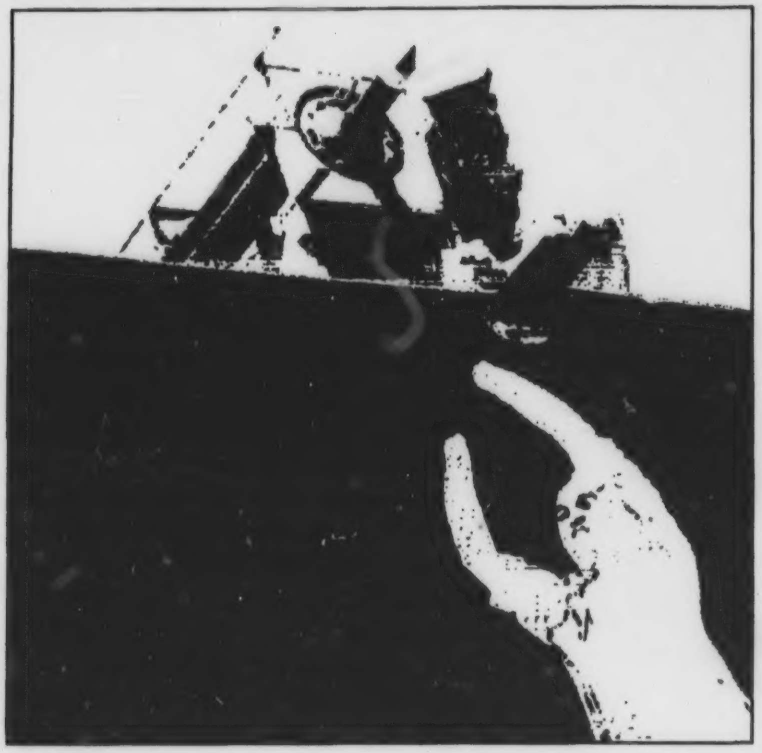
B. F. Peters

The Metals and Chemistry Section was established at the Pacific Naval Laboratory by the Defence Research Board in 1952; senior Naval personnel had identified the need for a materials laboratory to serve the Royal Canadian Navy in the Dockyard on the West Coast. The Navy's vision was that the laboratory would do more than just serve their immediate materials-related needs; the Section should also be part of a research and development facility to ensure that it remained current in materials science and engineering. Ralph Barer, who was appointed by Dr Fred Sanders, the Superintendent of PNL, to assemble and develop the new materials section for his laboratory—a third floor was added to the planned new PNL building for that purpose—wanted a scientific oriented staff which would get its hands dirty with real Naval problems. The materials laboratory was designed by Ralph Barer to be small, involving about 15 scientists and technicians, to make it efficient.

Members of the original team included Jack Carson who led the Corrosion and Paints Group and who had been working at PNL in corrosion science since 1950; Ray Brown who advanced the paints science work (and later moved to Halifax to subsequently become Head of DREA's Dockyard Laboratory); Art Anderton—his replacement; Clint Waggoner who led the Inorganic Chemistry Group; and Dick Sewell who led the Organic Chemistry Group activities. Two metallurgists, Jim Franks and Don Schaefer worked in the laboratory for periods before Frank Peters joined the Section in 1955 to serve in metallurgical failure analysis and in nondestructive evaluation studies. The scientists were supported in the early years by the following chemists and technologists: Lanny Yee, Harry Dominique, Jane Schofield, Gerry Vincent, Gwyn Owen, Ray Buckett, Bill House, Don Tweedhope and Ralph Temple. Others who later worked in the Section included Lenard Engst, Gary Dodd, and military officers LCdr Chuck Hase, LCdr Ken Moore and Capt Brent Marsh.

The main role of the original Metals and Chemistry Section at PNL was to serve the Royal Canadian Navy with its day-to-day materials concerns in corrosion, paints, chemical analysis, failure analysis, safety, material selection and nondestructive testing. The chemists served in many ways: conducting routine analyses of metals, divers' air, boiler chemicals and oil; developing techniques for analyzing materials; and conducting complicated diagnostic investigations on such things as shipboard fires. A memorable service to the Navy involved Dick Sewell and Lanny Yee spending a weekend analyzing material found in a sick sailor's stomach—an activity that saved his life. For his work over the years, and for his many analytical investigations, Lanny was presented with an ADM (Mat) Merit Award.

The Laboratory also served the Canadian Navy with a radiographic evaluation service. The first Canadian Forces radiographic standard for ship welds resulted from this work and was developed at PNL by Ralph Barer and Jim Franks from radiographs taken by Ralph Temple and Don Tweedhope. This, incidentally, was some fifteen years before a group of young Air Element officers convinced their management in NDHQ that these modern NDE techniques should be utilized by our Air Force. (The Navy's decision to obtain DRB scientific and technical support brought it many early benefits). The success of PNL's radiographic work cannot be overemphasized; using the standards, the DDE hulls welds and high pressure steam welds were kept free from serious defects and, as a result, served the Canadian Forces with relatively few problems, and no serious accidents, for 40 years.



Don Tweedhope (top) and Ralph Temple conducting radiographic examination of DDE hull welds in 1954

Because of PNL's involvement in radiography, and because the industrial sector was not yet using this modern technology, PNL was asked by the provincial government to X-ray some structural welds on the first of their new BC Government ferries under construction at Victoria Machinery Depot shipyards. The Lloyds Registry had apparently required some of the more critical welds be radiographed before the hull was launched; however, this requirement had been overlooked until a few days before launching. Ralph Temple and Don Tweedhope performed the radiography, taking fifteen radiographs, each covering seventeen inches of weld, a tiny fraction of the thousands of feet of weldment on the ferry hull. The radiographs showed 100% incomplete penetration (that is, the two welds from the two sides did not meet, leaving a crack-like defect at the centre of the weld). These defective areas were subsequently repaired, because one couldn't live with that defect. PNL was asked to re-examine them and the welds were found to be sound and free from the incomplete penetration. There was, of course, no time to inspect any more weldment and the ferry was launched. It is still running!

DRB management in Ottawa, in the 1950s and 1960s, was less than familiar with the detailed program at PNL in metals and chemistry. A visit to Ottawa in 1958 confirmed that headquarters staff did not know how many people worked in materials at PNL nor did they know what they might have been doing. The materials technology work at PNL was, for the most part, clearly a grass-roots effort directed at Naval needs and initiated by Ralph Barer and his staff. It was some years before headquarters started to become actively involved in the running of the marine materials laboratory.

An engineering "service" laboratory within the Defence Research Board was, of course, a bit of an anomaly since the DRB organization was research oriented; however, PNL's

Superintendents honored DRB's commitment to the Navy—which had originally agreed to create the positions for the materials laboratory at PNL if DRB managed and funded its operation. The Laboratory was a good setting for the Section's mixed activities of service and development work. The materials scientists became participants in the Laboratory's healthy seminars. They also enhanced their research interests—important for promotions—and they were later allotted research and development money to fund contracted research and hardware developments in industry and universities.

Not surprisingly, some polarization took place at the beginning between NRE's Dockyard Laboratory on the East Coast and PNL's Metals and Chemistry Section on the West Coast. Being so much closer to Ottawa than PNL—travel was not easy then—the NRE Dockyard Laboratory could interface with the Navy much more frequently. As a result, the NDHQ Naval materials people were sometimes less warm to PNL's views, particularly on paints and cathodic protection. However, in the early days, the Navy on the Pacific Coast was relatively independent from the East Coast, and the engineers in the Dockyard and the scientists at PNL were usually united in their support of one another. A strong West Coast team spirit was fostered over the years, to the benefit of the Fleet. Corrosion and Paints Group personnel were, over the years, very active and influential on the Navy's Committee on Corrosion and Fouling, and a number of members served as Secretary (Jack Carson, Art Anderton, Ray Buckett, Derek Lenard, Jim Moores). This Committee, in the early years, was chaired by an interested Naval Commodore, and PNL's science-based recommendations were highly regarded. As well as that Committee sponsoring annual meetings on the Coasts and in Central Canada, it also organized an international Inter-Naval Corrosion Meeting which was held every four years; and at which PNL personnel often presented briefs on their scientific investigations.

Jack Carson (front) joined as corrosion specialist in 1950. In back Harry Bell and John Smith.

For example, the historic scientific work by Ray Brown involved evaluating the effect of cathodic protection on paint. Cathodic protection, which was developed in Canada—at NRE on the East Coast—required an adhering underwater paint system to make the protection system an engineering reality. Ray Brown, and later Art Anderton, studied the cathodic delamination of the underwater paint systems. Art Anderton, in conjunction with Union

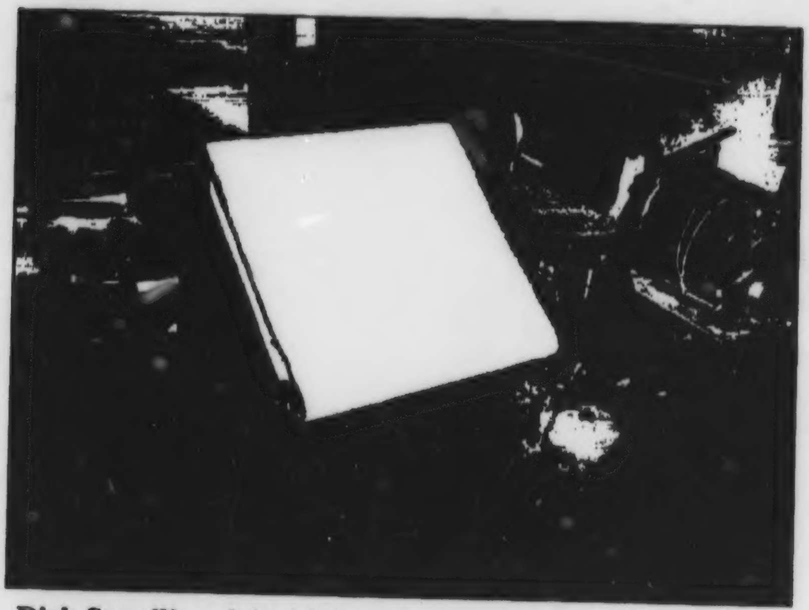
Carbide, developed the currently used aluminum vinyl anti-corrosive paint, a coating which is resistant to the debonding effects of cathodic protection. This paint development, coupled with the implementation of scientifically designed cathodic protection systems by Jack Carson, led in the 1960s to the extension of the period between drydocking of Canadian Forces warships from six months to four to five years.

Art Anderton is recognized in the international literature as the person responsible for determining the mechanism of copper conversion, a mechanism that was responsible for many of the underwater hull paint failures experienced around the world. But PNL's marine paint development work is even more noteworthy for its huge economic impact; more than simply reducing the costs of drydocking and painting, the PNL work resulted in one or two additional warships being made available for Naval service at all times, ships (now costing hundreds of millions of dollars each) which the Canadian taxpayer did not have to buy. It has been noted that the real savings from PNL's underwater paint work has probably paid for much of the entire research investment at DREP throughout its lifetime.

Jack Carson's early corrosion engineering and cathodic protection research and development work was pioneering in character. Not only did his studies ensure that the cathodic protection systems on Canadian Naval vessels were engineered satisfactorily, which brought considerable economic benefit to the Canadian Forces and Canada, but his work received international recognition for DND; the National Association of Corrosion Engineers (NACE) chose Jack Carson's paper entitled "Principles of Design of Cathodic Protection Systems for the Hulls of Active Ships" as the classic reference paper for the design of cathodic protection systems on ships. He established himself as an outstanding corrosion engineer, impeccably honest and fair to all.

Anti-corrosion work by Jack Carson on passive shaft grounding, undertaken with Ray Bucket and Don Evans in the late 1950s, led to the invention and patenting of an active shaft-grounding device, originally named DROPAPROP. The use of shaft-grounding systems became increasingly important on ships, and units were manufactured and sold by Davis Engineering in Canada. Canadian Forces ships sent to the Gulf were fitted with shaft-grounding devices to reduce their susceptibility to mines. Units were also sold to the USN, the UK Admiralty and other foreign navies.

Ray Buckett was corrosion technologist in early days



Dick Sewell's original laboratory model of the Slick-Licker

Another PNL patented invention which led to the production of a working system was Dick Sewell's "Slick-Licker" for cleaning up oil spills. It was based on the important concept that an oily rag will attract oil and repel water. A model of a device was first constructed and demonstrated at the Defence Research Establishment Pacific (DREP), the Establishment's new name in 1967, using an old $5 washing machine, typical of Dick's "old school" inventive style. Subsequently, a prototype unit was constructed with DREP funds. This unit became well known when the Royal Commission, reporting on the clean-up after the huge "Arrow" oil spill on the East Coast, found that only one of the more than one hundred inventions used to remove oil from the water and beaches worked; namely, the Slick-Licker. Because there was little interest by the Defence Department in oil spills in those days, the patent rights for the unit were given to the inventor, who with his brother formed a company to produce the units. Larger more-aggressive international companies soon found ways of circumventing his patent, and many "clone" devices were constructed and utilized by major harbours around the world, using the principle of Dick Sewell's patent. Dick was presented with a DRB commendation and a substantial financial award for his significant work in oil spill clean-up technology.

At that time the South American fuel used by the DDEs on the West Coast contained considerable amounts of vanadium with the result that the superheaters on all the DDEs became gummed up with refractory-like vanadium oxide deposits. This serious situation was resolved by Dick Sewell who devised a peroxide chemical cleaning method which enabled engineers to remove the thick sticky deposits in a matter of hours. The economic benefits of this chemistry-related work for the Canadian Navy was then very significant; the West Coast DDE superheaters did not need to be replaced.

Dick also recommended, after the failure of main propulsion diesel engine bearings on a CF ship was attributed to the ingress of sand from sand blasting in the Drydock, that an ice blasting apparatus be developed, work which was initiated by Jack Carson and later advanced by Terry Foster. Commercial units built in Victoria as a result of this thrust, while not particularly useful in some marine applications, are now being used in an automobile manufacturing assembly line in Detroit to de-burr gear parts. In addition, some units were purchased by Japanese Airlines; ice blasting has great environmental advantages over other aircraft paint stripping methods.

But Dick Sewell was primarily a classical inventor. Among other things, he recognized the need for divers to know how much longer their Clearance Breathing and Diving Apparatus

(CBDA) would be effective, and developed and patented, with Bob Chappell and Lanny Yee, a device that could measure the effectiveness of the soda lime scrubber while using the CBDA. Some of his inventions were less memorable, like the devices he proposed for walking on water, or the survival suit he created for sailors. Dick was probably best known for his wit—he was the Section's Poet Laureate for many years—and his land investments; he always noted "They just don't make it any more."

Lanny Yee also brought much pleasure to the laboratory with his personal entrepreneurial endeavors, some successful, others not. For example, after teaching a course at night school, he wrote a book on Chinese cooking entitled "Let's Cook the Chinese Way" which was very popular, selling about 70,000 copies. He also decided to try to grow mushrooms on sawdust without horse manure but that did not work too well. For a period of time he had a private fish farm using a couple of back yard swimming pools, and delivered fresh fish to restaurants each morning on the way to work.

Dick Sewell, Ralph Barer and Ray Buckett started an investment club at PNL in the early days, and the staff had great fun meeting regularly to see how their penny stocks (which made money) and their blue chip stocks (which lost money) were making out. Frank Peters was the first President of "Scientific Investors;" he did not get the job because of his extensive experience; he had never bought a share in his life before joining the club.

Early research activities in the Inorganic Chemistry Group led by Clint Waggoner—who was known for his discipline and his detailed, accurate and reliable work—centred on the development of various chemical analytical techniques which were needed to address a number of concerns of the Canadian Forces; for example, they were used for verifying metal alloy specifications (many specialized techniques and procedures developed) and for determining oil slick sources by checking on trace amounts of various constituents. Clint's historic work was then directed at oil analysis to detect minute amounts of wear debris, for engine health monitoring. This ultimately led first to the introduction and then to the widespread use of the Spectrometric Oil Analysis Program (SOAP) by the Canadian Forces. In this program, oil samples were taken periodically from equipment and analyzed for small traces of wear metal, to establish the condition of the machinery. Subsequent DREP research led to the use of Ferrography as a complementary method of oil analysis (where the metallic particles in the oil

Clint Waggoner (centre) receiving totem pole from ASM Chairman, Matt Gray, after giving presentation to Vancouver Island Chapter of ASM. Ralph Barer stands at right.

Harry Dominique with atomic absorption equiment

Lanny Yee in chemistry laboratory

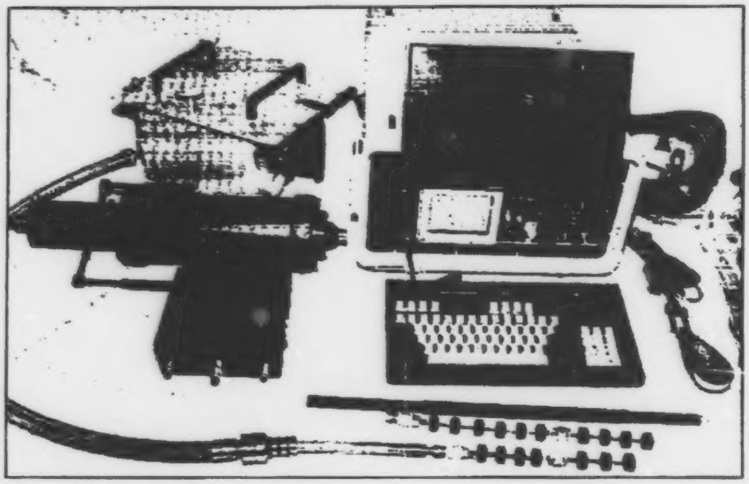
are separated out and distributed according to size), a technique which was then transferred to the Air Element. Filter debris analysis techniques (FDA), first introduced to evaluate DDE main engines of the 1970s, were subsequently developed for aircraft usage by Harry Dominique.

As with so many novel developments, such as the Slick-Licker, SOAP and others outlined above, once they are in place, most people today think that they are so obvious, they must have always been around. This is also the case with the application of nondestructive evaluation (NDE) to the marine boilers of our Canadian DDEs. When Frank Peters proposed that the expensive and destructive "Wear and Waste Program" which had been used by the Admiralty for a hundred years be replaced by NDE, there was at first strong opposition from Naval traditionalists. But at the 1965 Inter-Naval Corrosion meeting, the UK strongly supported PNL's NDE proposals and work as "pioneering technology" and stated "that we must continue this work and do our utmost to arrive at proper nondestructive tests in lieu of having to hack the boiler to pieces at intervals." PNL's early approaches involved radiography, borescope inspections, and the use of a Thulium 170 nuclear gauge (invented by Frank Peters).

Then, later, when ultrasonic transducers were miniaturized, John O'Malia, Simon Nelson and Barry Greenwood created two ultrasonic units for the small steel tubes. The Admiralty, at that time, stated that ultrasonic inspection of superheater tubes was "not possible." Frank Peters' approach had additional foresight; immersion ultrasonics was proposed and utilized (the tubes were flooded with water) so that units could ultimately be automated. Canada, with this DREP work, led the way with our Allies in this technology, bringing large economic benefits to the Canadian Forces and Canada's Allies.

The Canadian semi-automated immersion ultrasonic unit, first developed by CTF Systems, also received considerable international commercial attention. The Ultrasonic Boiler

Inspection System (UBIS) was borrowed by the USN to evaluate some of its ship boilers before the ships were sent to the Gulf (in 1990). Also, the up-dated UBIS system developed for DREP by Lambda Technology competed with other inspection systems in North America in 1991 on a "dummy" boiler constructed by a consortium of pulp companies—including Proctor and Gamble—and won the competition "going away," showing that Lambda, in conjunction with DREP (Barry Greenwood), had developed the best such unit in the world. It should be added that Barry Greenwood was the recipient of an ADM (Mat) award for his work on this development along with his development of techniques for detecting cracks in superheater headers, a serious problem in the DDEs in the late 1970s.



Ultrasonic boiler inspection system developed at DREP and now used commercially

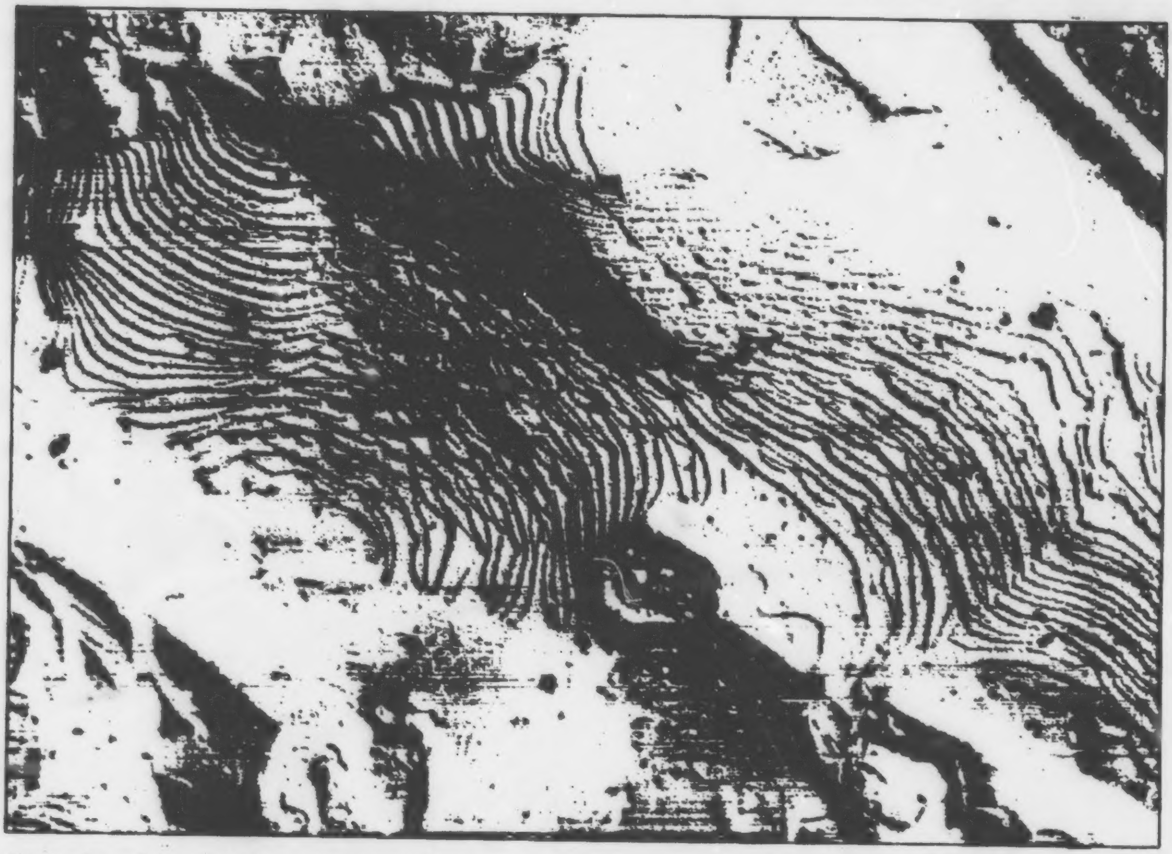
Some of the materials work proved to be both cost beneficial and reputation enhancing. PNL showed that the stress corrosion cracking failures of the superheater tubes on one of the DDEs had resulted because the superheater tubes had not been stress relieved by the manufacturer before being fitted into the headers. The Royal New Zealand Navy subsequently had similar failures, confirming the PNL work and referring extensively to it while resolving their own problems. A compilation of stress corrosion cracking investigations was subsequently presented at an international conference on corrosion in New York with the result that the corrosion literature now refers to that paper by Frank Peters, Jack Carson and Ralph Barer when mention is made to bird droppings being responsible for stress corrosion cracking of brass in the marine environment—not exactly the notoriety that the authors were looking for.

Stress corrosion cracking (SCC) failures were shown to be more common than some thought. One day, John O'Malia was told about a brass fitting that leaked on the propane tank of a friend's new trailer, and wondered why. A metallographic examination of the fitting showed that it had failed by stress corrosion cracking. It was reported, also, that the fitting had been crack-free when the owner had bought the trailer a month earlier; he had then checked the fitting with a soap solution authorized by the Vancouver District Fire Marshall. When a piece of stressed brass was placed in a water solution made from that soap, the brass cracked in 24 hours. Subsequent chemical analysis showed that the solution contained ammonia (which caused the SCC of brass). One wonders how many accidents may have occurred because of gas leaks caused by such solutions; small boats were frequently reported to have experienced explosions in our harbours because of gas leaks.

Over the years, DREP's metallurgical diagnostic work became extensive and its recommendations were of considerable interest to others. Ralph Barer was the recipient, for example, of the Hot-Dipped Galvanizer's Association Medal for a proposal to use hot dipped galvanized scaffold clamps rather than the stress-corrosion cracking prone aluminum clamps then being used in industry and by DND. A number of the Laboratory's metallurgical investigations were, subsequently, compiled and written up by Ralph Barer and Frank Peters into a book "Why Metals Fail" which was published in 1970 by Gordon and Breach Science Publishers of New York and which has since undergone its fourth printing. It has also been used as a textbook at Queen's University. The book, which was highly commended by an Oxford professor in the "New Scientist," included early examples of electron fractography, a diagnostic technique first introduced to DND by DREP.

New replicating techniques for electron fractography were developed by DREP with the result that John O'Malia won the 1970 Canadian Metallographic Gold Medal including a cash prize for his electron fractographic exhibit based on his novel Lucite replicating technique. John O'Malia (and Frank Peters) also exhibited many of their electron microscopical photographs at a showing in Victoria's Open Gallery. John O'Malia was an excellent water color painter, winning many local prizes.

While the laboratory had many day-to-day problems to deal with, it did not remain stagnant scientifically. Jack Carson, Ralph Barer and Frank Peters were the first to introduce the important modern science of fracture mechanics (which addresses the question of the strength of a component in the presence of a crack) in DND. Fracture mechanics techniques were used to evaluate the properties of and the failure of the high strength (Maraging 250) steel used in the construction of the foils of Canada's hydrofoil, the FHE-400. The DREP work was



Canada-wide metallographic gold medal winning photograph by John O'Malia - using his "lucite" technique, he shows surface of hydrogen bubble in aluminum casting x 10,000

presented at an international symposium in England in 1973.

Electron microscopy work on fracture at DREP also led to some internationally recognized fundamental metallurgical research on texture formation. Frank Peters' Sequential Twinning Theory for explaining recrystallization texture formation in low-stacking-fault-energy alloys (such as brasses and bronzes), resulted in considerable research and international discussion—in the UK (Oxford), Germany, Denmark, Netherlands and Japan. Professor Wilbrandt, one of the world's recognized authorities in recrystallization science at Gottingen's "Institute Fur Metallphysik" started his review on "Recrystallization Texture," published in Physica Status Solidi in 1980, with reference first to Frank Peters' theory and to the considerable support that it was then receiving.

In the 1970s, before the Air Element had its own NDE facility at CFB COMOX, Don Tweedhope conducted radiographic examinations on aircraft and helicopters at the Base. His congenial presence there led to DREP being asked to conduct various other investigations for the Air Element, including studies of fracture—DREP's unique electron microscopy facility was used to show fatigue markings on fractured aircraft components—and corrosion. However, when failure investigation work was consolidated for the Air Element at the Quality Engineering Test Establishment in Ottawa, and when an NDT facility was set up at CFB COMOX by the Air Maintenance Development Unit at Trenton, DREP's Air Element role became almost completely one of research and development.

Don Tweedhope, who served the Section in NDE and metallography, was "a legend in his own time." Among other things, Tweedie had an awesome sense of timing. When a PNL speaker was about to be introduced at an international conference in Montreal to give his paper—on the ultrasonic evaluation of ships' bearings—he was handed a telegram which read, "Recent results show your conclusions to be erroneous, but best of luck anyway. Stop." That served as a good introduction to the talk.

Tweedie was competent, but often felt overworked. He had to work alone and there seemed little chance of his getting any additional help. Any new staff would generally be assigned to research projects, not routine service to the Canadian Forces. One day, Don was called upon by the Laboratory to X-ray a secret Russian device on the following day. Recognizing his opportunity, he got his colleagues in the Dockyard to phone him the next day to ask him to do NDE work. The Cobalt Hut was full of interested physicists, including the Chief who waited patiently in Tweed's office as the calls came through and as Tweed was deflected from his X-ray task. A few weeks later, the Chief authorized one of the Laboratory's positions to be allocated for an assistant technologist in nondestructive evaluation.

And sometimes Tweedie pushed his humour a little far—like when the Management Committee of the Laboratory met to cut costs and decided to reduce the number of telephones at DREP by two. One of Tweed's four telephones had to go and he was not happy. About a month later, when Frank Peters returned to his office, Room 111, he found a telephone technician removing his one telephone. "What are you doing?", Frank asked. The telephone worker showed Frank his work order to remove the telephone in Room 115. Frank opened the door to show him he had the wrong office only to find that his door had had its number changed from 111 to 115!

While Naval colleagues remember Ralph Barer "and his band of merry men" most for their willing support and contributions to the solutions of the technical problems on their ships, others in Victoria remember the active part that the PNL materials scientists had in technology education. For example, Ralph Barer and Frank Peters gave free lectures to radiographic inspectors in the industrial sector before CGSB specifications and classifications were in place.

Ralph Barer was also the founding president of the Vancouver Island Chapter of the American Society for Metals (ASM), and he was followed in that office by Clint Waggoner and Frank Peters. In addition, PNL personnel—Ralph Barer, Jack Carson and Frank Peters—volunteered their time and talents to teach ASM courses to those interested in up-grading their metallurgical and corrosion knowledge in greater Victoria and on the Island. Many of the DREP materials staff also served as Science Fair judges from time to time, and Frank Peters served as the Engineering Chairman for the Canada-Wide Science Fair when it was held in Victoria.

PNL's materials engineering staff also made lasting contributions to society at large. Ralph Barer was convinced that the medical and physics communities in the early 1950s were not correct in their indifference to the potential damaging effects of X-ray radiation on one's health. Accordingly, he encouraged his radiographers to get as little radiation dosage as possible when conducting X-ray and gamma-ray evaluations, something for which they are now thankful. There was considerable resistance to Ralph Barer's conservative views within DRB. He also made a pest of himself at Victoria Jubilee Hospital by trying to get the nurses to put lead aprons on and stay outside the area in which patients were being X-rayed (not their practice then); for that, the doctors had him physically removed from the hospital. The Vice-Chairman of the Defence Research Board, in the presence of the Canadian Surgeon General, acknowledged sometime later that Ralph Barer was correct in his concerns, and that the "establishment" had been wrong.

By the mid-1970s, after the laboratory had become part of ADM (Mat) and was managed by CRAD, a few more staff members were taken on to support the growing marine materials activities at the Laboratory, in what was now called the Materials Engineering Section at the Defence Research Establishment Pacific (DREP): Bob Coote replaced Frank Peters when he took education leave in the UK, John O'Malia and Barry Greenwood joined Don Tweedhope's nondestructive testing team; Jim Moores and Doc Schmitz joined the Inorganic Chemistry Group, Bob Rowland joined the Organic Chemistry Group; and Jim Maxwell and Tom Nikiforuk joined the Corrosion Group. Later, Dr Jim Matthews transferred from DREV to the Metallurgy and NDE Group.

Although the Ottawa management changes placed enhanced emphasis on research and development—as opposed to consulting and operational support to the Navy—Ralph Barer, while supporting R&D which had clearcut relevance, ensured that direct support to the military remained a high priority. Also, while CRAD promotion policies somewhat discouraged scientists from working on engineering problems experienced by the military, the Laboratory would periodically get urgent requests from CRAD to list and describe recent investigations which were of direct value to the military. As a result, at times the organization appeared to support two different policies.

Barry Greenwood ultrasonically inspecting DDE mast for cracks

Advanced metallurgical fracture research, first initiated by Ralph Barer and Jack Carson on the Maraging 250 steel, was subsequently conducted by Dr Jim Matthews, and then by Dr

Jack Morrison and Ken KarisAllen who published extensively in the fracture literature. They studied the fracture resistance of structural steels for ship construction. Under normal operating conditions, construction steels are often capable of withstanding substantial amounts of ductile tearing and fatigue cracking. However, the same material can suffer brittle failure as a result of dynamic impact, low temperatures, and loss of mechanical constraint, particularly in welded sections. Jack Morrison's investigations of ductile fracture in marine steels led to a new model for describing crack extension under limit load conditions. In later years metal failure analyses were conducted at DREP by Barry Greenwood, Ron Myllymaki and Jack Morrison.

Novel nondestructive evaluation research was also conducted by Jim Matthews and Merv Black in the late 1970s on variable depth sonar (VDS) cable failures using acoustic emission techniques. Their work led to the development of an acoustic emission device (patented with George Schattschneider) which could warn VDS operators about impending cable failures. A redesign of the VDS cable system precluded the need for this advanced device. Jim also patented a system for reterminating cables at sea for which he was presented with a Suggestion Award. Before transferring to DREA's Dockyard Laboratory in 1980, Jim Matthews also developed a Peak Dynamic Stress Indicator, which he patented with George Schattschneider, to record stresses in dynamically loaded structures.

It was one of Jim Matthews' failed fatigue specimens which was later used to create the "Ollie" award (named after Oliver North), an award given to staff members who showed particular ingenuity at making things go wrong. For example, Mike Lucking received it for his "operation" of the Composite Group's computer controlled MTS system and Jim Moores received it for mixing up Celsius and Fahrenheit scales when heat treating aluminum specimens. The Ollie Award, incidentally replaced the Laboratory's "Boob of the Month" Award, which was lost to the Laboratory when it was awarded to a CBC cameraman who forgot to take the cover off his lens while recording DREP activities.

In the late 1970s, as a result of a technology area review in Ottawa, Materials Technology was given the TP-26 "Technology" status as well as the role of Establishment of Primary Interest for Materials Technology in CRAD. Accordingly, additional staff were hired to address Air Element as well as Marine Element materials research and development concerns. Dr Ken Street joined DREP staff to create a Composites Group and was later joined by Alan Russell, Mark MacDonald, Ernie Jensen, Arleen Hendrix and Dr Mike Lucking. Bill Sturrock led a new Nondestructive Testing Group which grew to include Ken McRae, Jeff Boyd, Al Gillespie, Terry Miller, Murray Acton and John Cornes. Most fortunately, two new Air Element military positions were created in the Composites and Nondestructive Evaluation Groups and numerous officers were appointed over the next dozen years; namely, Maj Ray Raoux, Maj Ed Karkut, Maj Al MacRay, Maj Rick Finlayson, Capt Chris Bowers, Capt Scott Ferguson and Sgt Bob Watson. Dr Terry Foster had joined the Corrosion and Paints Group. At that time, the other groups also started to address Air Element as well as Marine Element materials problems.

It might be added that the materials laboratory had always, on an informal basis, supported other government departments such as the RCMP, the Coast Guard, and the Department of Transport. PNL staff members were, for example, very active in the 1965 investigation of a CP Air DC-6B crash which took place between Vancouver and Prince George and in which more than fifty people were killed—a bomb had been detonated in an aft toilet. At the Coroner's Inquest when Ralph Barer was being questioned on his metallurgical report of the investigation, manipulative lawyers asked him to comment on some photographs of some metallurgical fractures he had not previously seen. His response, "Would you ask a doctor to diagnose a patient from a photograph?" brought laughter from the spectators, and the lawyers had no more questions.

As well as conducting in-house research and serving as Scientific Authorities in contract research in their expanded roles, various materials personnel also became active in international technical societies such as CIC, ASM, NACE, ASTM, ISSC,[1] and the Pan Pacific Non-destructive Testing Committee as well as national working committees such as the DRB University Grants Committee and various Canadian Government Specification Board Committees on paints and NDE. In later years, DREP personnel also served on other DND committees such as the Naval Platform Research and Development Committee, the Aircraft Structures and Materials Advisory Committee and their subcommittees.

Dr Derek Schofield, CRAD, (centre) presented TTCP Achievement Awards to Drs Ken Street (left) and Jack Morrison (right)

In addition, in the 1970s, DREP Materials Technology staff began to serve Canada and the Department of National Defence on a number of international defence committees, a role that increased over the years. Most of these activities centred in the Technical Cooperation Program (TTCP), a co-operative research and development activity between Australia, New Zealand, Canada, the United States and the United Kingdom. Ralph Barer, Frank Peters, Ken Street, Clint Waggoner, Jack Morrison, Greg Luoma, Bill Sturrock, Terry Foster, Ken McRae and Alan Russell all subsequently served on one or more technical committees as Canadian National Leaders. As a result, they gained a good insight into what was going on internationally in materials technology, and found that some of the activities at DREP, with its small staff, were having significant impact internationally. A number of the Materials Technology Section staff members were, accordingly, presented with TTCP Merit Awards; namely, Jack Morrison, Ken Street, Bill Sturrock, Allen Russell, Greg Luoma and John Cornes.

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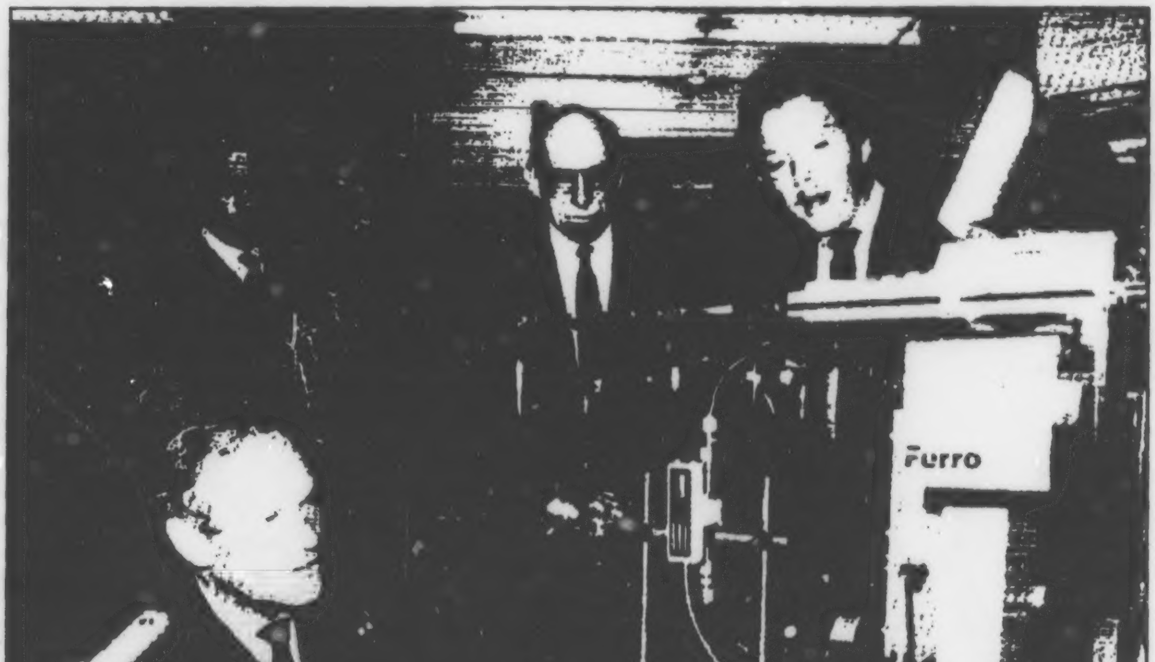
[1] Chemical Institute of Canada (CIC), American Society of Metals (ASM), National Association of Corrosion Engineers (NACE), American Society for Testing Materials (ASTM), and Internationall Ship Structures Committee (ISSC).

As a result of DREP's new role in Air Element materials R&D, Dr Ken Street led his Composites Group in delamination fracture mechanics, composite defect repair, and environmental degradation of composites; and Bill Sturrock led his NDE Group in advanced ultrasonics, eddy current array research and real time radiography. Bill Sturrock was particularly successful at extracting Tasking money from the Air Element for his NDE development activities. Air Element paint work was addressed by Dr Terry Foster and included the application of plastic media blasting and ice blasting to Air Element components. Dr Greg Luoma developed an adhesive bonding kit, utilizing his superior "Luomapoxy" adhesive, for repairing aircraft. Dr Jack Morrison and Dr Zhenhua Zhai studied aluminum-lithium alloys, part of an on-going international TTCP assignment. The importance of this latter work to the Air Element waned when the decision was made to defer the purchase of new helicopters for our ships. Dr Frank Peters, in latter years, served on the Structures and Materials Panel of NATO's Advisory Group on Aircraft Research and Development.

Clint Waggoner, Ken McRae and Bruce Kaye introduced a scanning electron microscope/X-ray analyzer facility at DREP which proved to be a very powerful tool for wear particle studies. A critical wear-resistant alloy component in the CF-18 F404 engine was, for example, identified by their studies. Clint's historic spectrometric oil analysis studies, originally directed



Greg Luoma showing Ferroscan (patented by Clint Waggoner) to the First Sea Lord, Sir William Stavely-Frank Peters standing in centre

at marine concerns, but later transferred to the Air Element, also led to research into an on-line monitor, one that could give "real time" (instantaneous read-out) indications of wear in the oil from a sensor in the oil line. He subsequently patented the Ferroscan in both Canada and the US, jointly with "Sensys" who had been contracted to do the research for DREP.[2] This work led to additional contracts with "Gas Tops" and to the development of an on-line Total Debris Analysis system which was able to monitor both ferromagnetic and also non-magnetic material in the oil. This latter unit was chosen by Pratt and Whitney for incorporation into their successful bid (August, 1991) on an engine for the USAF's new multi-billion dollar F-22 advanced tactical fighter (ATF) development. The potential economic importance of this unit cannot be overemphasized.

The science of fracture mechanics was applied by Ken Street and Alan Russell to the problem of delamination defects in advanced composite materials such as the graphite-epoxy material used on the CF-18 aircraft. A new test method was developed by Alan Russell for the assessment of the delamination fracture toughness of laminate materials; that is, the end notched flexure test. This technique was approved as an ASTM standard and is, in addition, used and referred to extensively in Europe by those involved in composites research. The results from DREP work, using this technique, enabled McDonnell Douglas to evaluate the criticality of "large" delaminations discovered in the fixed trailing edge wing skins of USN and Canadian F-18's. McDonnell Douglas experts reported that Alan's work was "probably the most useful research anywhere that is directly applicable to damage tolerance of FA-18 composite materials." A Pentagon spokesman stated that this technology "ensured that our governments are not held hostage by the aircraft manufacturer."

Ken McRae

Combined work by Alan Russell, Chris Bowers and Greg Luoma also led to the development of an epoxy injection repair method for recovering the fracture strength of damaged graphite-epoxy composites. Using ultrasonic techniques developed by Ken McRae, it was possible to view the repair process as it took place. Fracture studies showed that the original strength of the composites had all but been recovered by the repair process.

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[2] In addition to the Ferroscan developments (a six-year project), the Inorganic Chemistry Group conducted an extensive (three-year) wear assessment of army vehicles, including the Leopard tank, and a four-year fleet-wide (Cold Lake, Bagotville and Baden-Solligen) investigation of CF-18 F 404 engine wear characteristics using all the advanced methodologies developed earlier. These achievements were recognized by requests for invited presentations to a CRAD Special Briefing in 1981, AGARD in 1982, an Army Seminar in 1984 and the CRAD Review'84.

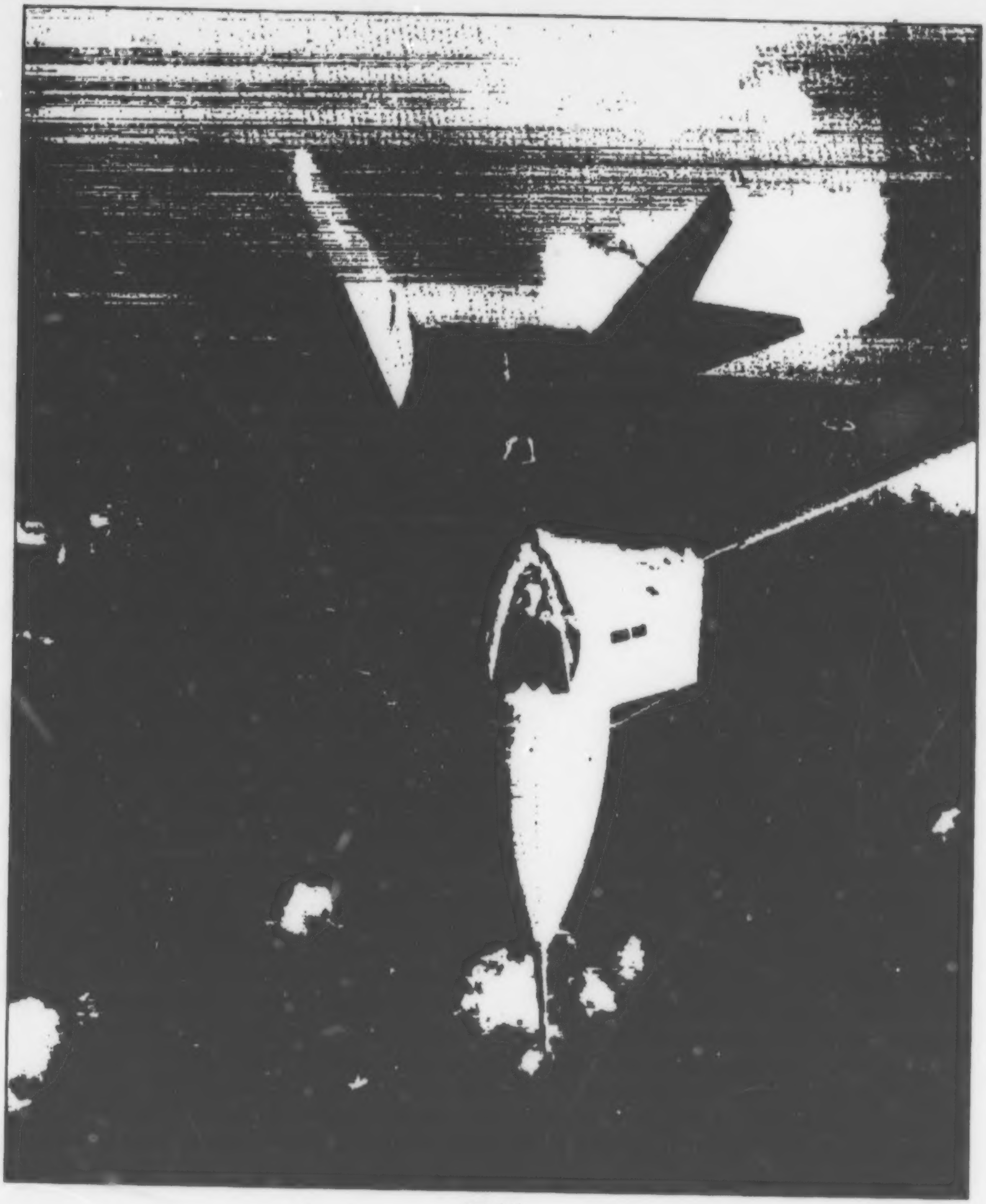
The first DND Composite Materials Workshop was organized by Ken Street in 1983 and successfully gathered together about 100 people from DND, universities and industry to enhance the development of the DND technology resource base. The Proceedings remain a classic today when partnering has become such a key element in CRAD policy.

Bill Sturrock and Ken McRae's work with Barrodale Computing Services of Victoria to develop signal processing and imaging software for the ultrasonic testing of composites was also very successful. The Barrodale software "SPUD" was sold commercially to Boeing and British Aerospace Corporation. The software, used in conjunction with an automated ultrasonic scanner, was able to accurately characterize the extent of small delamination defects in the wing skin of a CF-18 aircraft, something that one was not able to do with conventional ultrasonic equipment. Ken McRae and Terry Miller were presented with the R.J. Herbert Award for best CASI Conference paper for their presentation of DREP work on signal processing and data acquisition for ultrasonic nondestructive evaluation of aerospace materials. Ken McRae, because of his publications and expertise, was also asked to serve as an expert witness at a litigation trial in Philadelphia between two ultrasonic equipment manufacturers in the USA.

When the "old guard" started to retire around 1980 a number of the newer scientists and technologists were already taking more prominent roles in the Section. Dr Greg Luoma took over the leadership of a combined Chemistry Group which then also included Bruce Kaye and Alison McKenzie. Dr Derek Lenard transferred from DREA and took over the leadership of the Corrosion and Paints Group which was then supported by Jim Moores and Geoff Blenkinsop. Dr Jack Morrison transferred from DREV to lead the Metallurgy Group, which then included Ron Myllymaki, Paul Martin, and later Ken KarisAllen. Dan Liesch joined the nondestructive testing team which was later led by Barry Greenwood. Joan Stringer, the Section's longest serving secretary, had that role until the Laboratory's closure.

The new staff was not to be outdone by its predecessors. A Canadian Forces need (for personnel safety) to be able to detect very low concentrations of toxic Otto Fuel vapor (the fuel used in torpedoes) led to the patenting by Greg Luoma and the development by RETECH of a novel system using a piezoelectric quartz crystal monitor, which was able to detect Otto Fuel vapor down to one part per billion (ppb). Some of these units were purchased by the USN and underwent successful trials. Greg was also responsible for important research on adhesives, research that led to the development of a patented superior epoxy cement, "Luomapoxy," and an injectable epoxy for repairing composites. Greg, a biochemist by training, kept current in his original field of study and was also responsible for directing a colleague to get a new and successful treatment for a special type of cancer he was suffering from.

In 1982, after the well-publicized superheater header cracking problems were diagnosed by Ron Myllymaki on our DDEs and many boilers had to be retubed, a commercial boiler manufacturer reported that it was not planning to stress relieve the replacement superheater tubes before installing them, because it felt that the stress relieving operation was costly and unnecessary. Having not done this kind of work for years, the company no longer had a good corporate memory. On urgent recommendations from DREP, NDHQ insisted that the heat treatment be performed and no problems subsequently occurred. The huge cost benefits to the taxpayer associated with having knowledgeable people who are close enough to the action to recommend proper measures is not normally recognized and emphasized. Non-heat-treated tubes would have started to fail within a year in all the boilers, at great additional cost to the taxpayer and at considerable embarrassment to the Navy. It might be added that DREP had previously recommended the use of oxidation resistant "high chrome" superheater tubes in the boilers and this change also resulted in a much more reliable propulsion system in the DDEs.



CF-18

In the mid 1980s the Chief, Research and Development proposed the elimination from his Branch of the materials activities on both coasts (which were seen to be "mature" technologies). At the same time, incidentally, the Canadian Government identified materials technology as one of three technology areas that was to receive much greater government support. In any event, CRAD deleted TP-26 "Materials Technology" from his list of formal CRAD "Technologies" with the result that the DREP materials activities became components of both the Marine Platforms and Air Platforms technology areas. This eased the CRAD pressure on materials activities at DREP; however, because there was no formal materials technology program, an anarchy soon developed within the Department with many DND-financed factions competing for the high profile materials research activities, and the influence of DREP's Materials Technology Section waned. Because DREP's Materials Technology Section had maintained its original mandate to serve the Navy—and DREP's marine materials program was, in addition, well co-ordinated with DREA and NDHQ, the military resisted the closure of the Materials Engineering Section on the West Coast and the Dockyard Laboratory on the East Coast. Accordingly, no further downgrading action in materials technology was taken by CRAD at that time.

In 1988, Dr Frank Peters returned to DREP from DREA to become Section Head, Materials Engineering (later Materials Technology). Subsequent appointments in the Section included Alan Russell as Leader, Composites Group, replacing Ken Street who had gone to CRAD/HQ as Director of International R&D Programs, and Dr Terry Foster as Leader, Chemistry Group; and the hiring of Dr Chuck Connor for the Chemistry Group, Dr Margaret Chadwick for the Composites Group and Dr Zhenhua Zhai for the Metals Group. Following the announced closure of DREP, Dr Chadwick was quickly snapped up by the Ford organization to work in their laboratory in Dearborn, Michigan.

In the latter years CRAD stressed the importance for its scientific staff to pragmatically serve the short term needs of the military. As a result, the Materials Technology Section was much closer to being in step with Laboratory policy. The Section was at the same time "tasked" by the Army to establish a "technology base" in materials. Also, the Section was encouraged to emphasize the historic as well as the more recent benefits that the Navy received by having a materials laboratory serve it on the West Coast. The Air Element, which had given support to DREP's materials program over the years with Tasking funding, and had participated in symposia organized by DREP (in NDE, Composites, and Aluminum-Lithium alloys), had—even in CRAD—no real long-term interest in a "distant" West Coast Air Element laboratory. Accordingly, and as the support to the Army was on a modest scale, only the Navy gave strong support to the Materials Technology Section when the closure of the Laboratory was being considered.

Derek Lenard and Jim Moores continued to show the value of DREP's involvement in corrosion engineering for the Navy. When the stainless steel propeller shafts on the new Torpedo and Ship Ranging Vessels (TSRV) experienced serious corrosion within twelve days of launch, private sector investigators gave the Navy misleading advice. The corrosion was, in fact, caused by stray currents and a shaft-grounding system was, accordingly, installed to ensure that the expensive problem would not recur. The related DREP work on the measurement of stray currents was also considered significant and novel by the corrosion science community.

DREP's corrosion-related work received important additional recognition in the strategic area of ship silencing. Research initiated by Jim Moores led to the development, by George Schattschneider, of a filter for the active cathodic protection system on our Naval vessels. Such filters were installed on our Canadian warships in the Gulf in 1991 to ensure that they were less vulnerable to mines. Jim Moores was the recipient of an ADM (Mat) Merit Award and the prestigious Public Service Commission's "Award of Excellence" presented by the President of the Treasury Board (given to Canada's top civil servants each year) for, among other things, his important contribution to the development of this device.

A new potentiostatic instrument, proposed by Derek Lenard, and patented by George Schattschneider, was designed at DREP to control up to fifty-six electrodes, all in the same test tank using a single auxiliary electrode. Neither the test tank nor the potentiostat needed to be electrically isolated from "earth" ground. The patented unit was so novel that when the first DREP paper on it was submitted to a refereed journal, its approval was postponed by an unbelieving reviewer until a second paper proving its success in a recognized standard situation was added. The new instrument reduced corrosion research and development costs dramatically and has also been of interest to Canadian industry.

As a result of DREP's reputation in marine corrosion science and engineering, the editor of the British Corrosion Journal identified the corrosion laboratory of DREP as "one of the important corrosion laboratories of the world."

In latter years, DREP's coatings research was conducted by Terry Foster. Chromate-free primers, needed because of the environmental problems associated with chromate-containing primers, were formulated, developed and patented under contract by Industrial Science Laboratories. These new environmentally-acceptable primers, could be safely used to protect the surface of the metal and to improve the adhesion of the paint. Dr Foster also became expert in the science of removing paint (plastic media blasting and ice blasting) and was asked by NATO's Advisory Group for Aircraft Research and Development (AGARD) to conduct workshops in Europe on that topic.

Successful work was also undertaken by Terry Foster, in co-operation with PEC in Vancouver, on the development of a biodegradable plastic, one that would degrade in sea water. The work centred in a patented blend of natural rubber and poly caprolactone. While biodegradable plastic was now no longer required by the Marine Element of the Canadian Forces because of changing environmental needs, commercial manufacturers—of disposable diapers and garbage bags—became very interested in the DREP-patented material.

Frank Peters presenting "Ollie" award to Jim Moores - Derek Lenard in foreground

Historic initiatives at DREP also led to the development, first by Seagold Industries and then by Hi-Tech Enterprises Ltd of Victoria, of reverse osmosis systems for producing fresh water from sea water. Early work resulted in the marketing of the first and only hand operated reverse osmosis system that could be used for emergency water production. Later work resulted in the development of a centrifugal (and therefore much more quiet) reverse osmosis system, a system (patented by Tony Moilliet and Dave Hopkin) that was given a successful Naval technical evaluation and which also received considerable Admiralty interest.

The day to day service to the Dockyard provided by the technologists in the Materials Technology Section contributed in large part to the Laboratory's reputation in the Navy. Remembered most in later years were the many chemical analyses conducted by Doc Schmitz, Bob Rowland, Bruce Kaye and Alison McKenzie; the radiographic analyses performed by Barry Greenwood and Dan Liesch; the paint and corrosion work of Jim Moores; and the metal failure investigations supported by metallography by Paul Martin. Accordingly, many Materials Scientists at DREP received many commendations from senior Canadian Forces officers as well as letter of thanks from others, for their resolution of specific problems. But the failure investigations remembered best by Naval officers were those in which a DREP diagnosis revealed that there was some inherent problem with the materials or systems used and that the failure was not, therefore, the result of negligence on the part of the Canadian Forces men involved. For example, one anchor cable failure which resulted in damage to a ship was shown to have resulted from a manufacturing defect, a diagnosis long remembered by the appreciative ship's captain—who later became an Admiral.

In conclusion, the Materials Technology Section of DREP was very successful, both in its prime role of serving the Canadian Navy as materials consultants in a wide range of disciplines and topics, and also in developing a recognized world class materials technology research and development laboratory. It performed vital service to the Canadian Forces on the West Coast by helping resolve many day-to-day materials concerns, thus giving reliability to the marine equipment and consequently helping to reduce costs. The value of good advice was also very important; without that, the Canadian taxpayer could have suffered significant financial losses in some instances. The Materials Technology laboratory at DREP, in addition, contributed significantly to many areas of defence science and engineering; for example, the development of underwater coatings and cathodic protection engineering principles, the assessment of delamination criticality in the composite materials on CF-18 aircraft, the introduction and development of the Ultrasonic Boiler Inspection System—both for the Navy and for Canadian industry—the introduction of SOAP technology both to the Marine and Air Elements, the development of SPUD, and the introduction of other patented hardware: the Slick-Licker, the Ferroscan, the Otto Fuel Detector, the centrifugal reverse osmosis system, the ice blasting system, Luomapoxy, the shaft-grounding units, and the active cathodic protection filter. Contractors in British Columbia benefitted in "Technology Transfer" while participating in these developments. Personnel at DREP were also of considerable service to the industrial materials technology community in Victoria. The model first proposed by senior Naval officers to have their West Coast Dockyard Laboratory associated with a research and development laboratory proved to be very beneficial.[3]

Most of those who worked as scientists, engineers and technologists in Materials Technology at PNL and DREP would say that they had had very rewarding careers.

---

[3] The model is still being supported by the Navy: in spite of the closure of DREP, the marine component of the Materials Technology Section continues to serve the Navy in Esquimalt in its historic role—under its new Section Head, Dr Terry Foster.

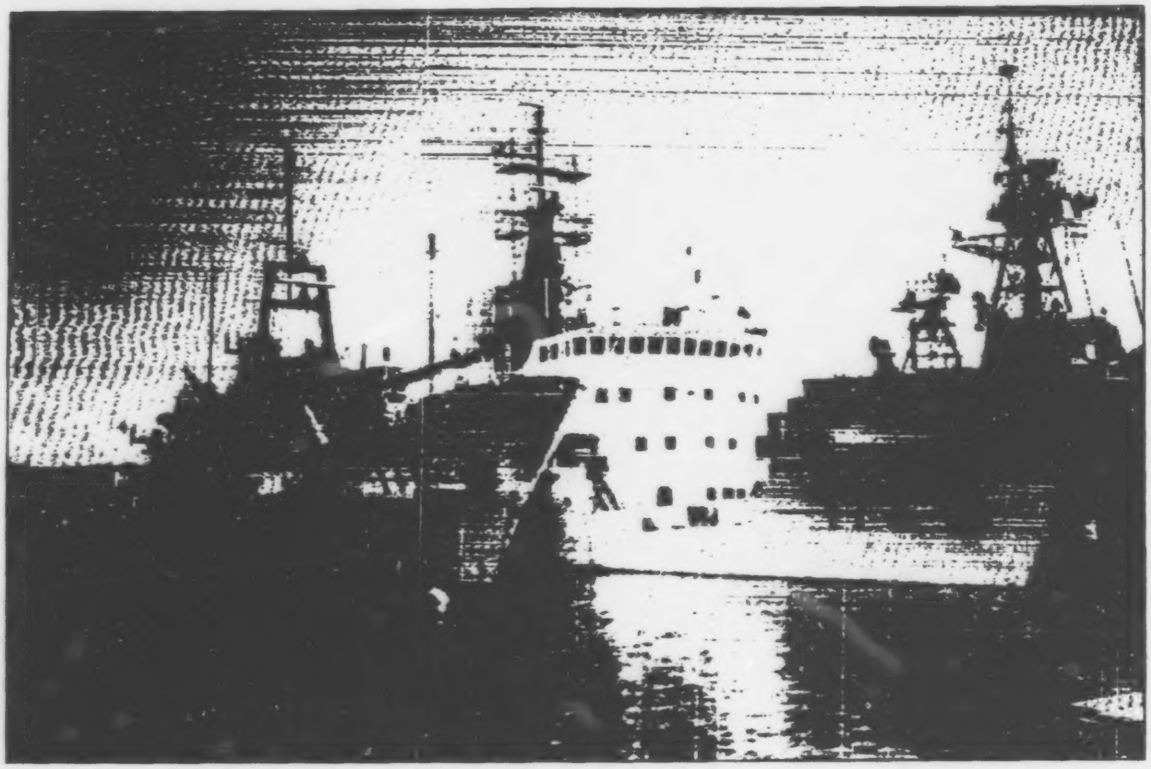
5. EPILOGUE

R.P. Chapman

As a result of rapidly increasing trade, the Pacific Ocean was becoming more important to the country economically. Geopolitical considerations indicated that the same was also taking place militarily, a view espoused by the Navy who have begun to station an increasing portion of their warships on the West Coast, with the intention of approximately equalizing the number on each Coast. This strategy ensured that the demand on the West Coast for a number of components of the DREP research program, particularly those associated with direct support to the fleet by materials technologists, would remain high and that some of the work would have to be conducted locally. The announcement in the Budget that the Laboratory was to be closed, placed severe constraints on how this demand was to be satisfied both in the near and longer term. It was decided that the research on ocean acoustics in the Pacific would be terminated, that on air-related materials research would be transferred to Ottawa, and the responsibility for the remaining elements of the DREP program would become the responsibility of DREA. Initially, in order to provide the maritime materials facilities and services required in Esquimalt, and to allow the completion of a number of specific tasks in MCM, MAD and Arctic surveillance, a new facility was formed, called the Esquimalt Defence Research Detachment (EDRD), a division of DREA, but resident in Building 199. This division, with Ken Street as Director, was to continue from April 1995 to April 1998, at which time all the programs except that in materials technology would be transferred to DREA in Dartmouth, Nova Scotia.

With the termination of the underwater acoustics program in the Pacific, the use of CFAV ENDEAVOUR on the West Coast could no longer be justified, so in August 1995 the ship was transferred east to substitute for the DREA research ship CFAV QUEST during a major refit, following which ENDEAVOUR would be retired from service. Similarly, with the transfer of the air-related materials program and equipment to a DND facility at NRC in Ottawa, there was no longer a requirement for Building 204—it was demolished in April 1996. After the closure was announced in February 1994, the staff had a number of options to consider. They could choose early retirement—facilitated by a buyout—apply for positions in EDRD or in some other element of DND or the Public Service, or go on leave without pay—thus maintaining eligibility for future employment in the federal government. Failing all of the above they would be subject to involuntary retirement—a situation which in fact did not occur. Of the 120 employees on staff at the time of the closure, 48 availed themselves of the buyout option, 55 were hired by EDRD, 11 went to other positions in DND—including 2 to the underwater acoustic surveillance program in Dartmouth, 1 each to air materials and the Directorate of Scientific and Technical Intelligence in Ottawa, and 2 to Operations Research in Winnipeg. Of the others, 2 joined a local university, 1 took up a term appointment at SACLANTCEN, 1 joined the National Archives in Burnaby and, tragically, 2 died in a flying accident.

By and large, members of the staff who did not wish to retire permanently were remarkably successful in finding other employment commensurate with their ambitions, skills



ENDEAVOUR (171) in Halifax, berthed next to QUEST (172)

and training. In retrospect, this is perhaps not too surprising; the staff tended to be highly educated, adept in using computers, and, as befits an organization specializing in field trials, highly independent and adaptable, all qualities of inestimable importance for coping in a downsized world. In addition, DND was quite responsive to the needs of the staff in providing alternative employment and career counselling. Thus, after recovering from the initial trauma, the staff coped very well.

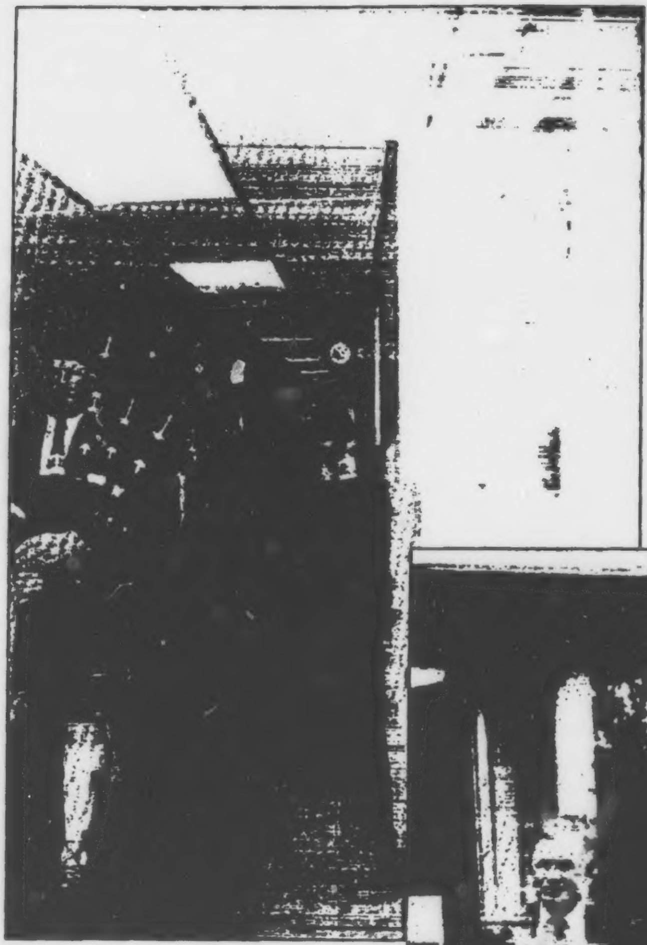
On 1 April 1998, further downsizing and adjustments will be required. EDRD will at that time be reduced to a Materials Technology Section, called the Dockyard Laboratory (Esquimalt), with a technical staff of 13 supported by a single administrative support person. The positions of the Director, 11 from Arctic Acoustics and 2 from Administration will be declared redundant. The remaining 30 positions will be transferred to Dartmouth. Once again the staff has a range of options to consider. In the earlier downsizing, the buyout was particularly attractive to those with either many or few years of service. As nearly all who met either of these criteria departed in 1995, most of those remaining are essentially in mid-career; thus making retirement unrealistic and departure from careers in which they had invested heavily, unattractive.

Of the 40 members of the staff who will be leaving EDRD, it is expected that 5 will accept a proffered buyout, 19 will follow their positions to DREA and another 6 will find positions elsewhere in CRAD. Of the remaining 10, it is expected that 4 will leave the public service and that 6 will obtain other employment with the Federal Government in the local area.

With this wide dispersal of staff, the only programs that will reach DREA relatively intact will be ship quietening and electromagnetic surveillance; route surveying, Arctic acoustics and MAD will be reduced to shadows of their former selves. Expertise, built up over decades, will be lost and would require much effort and several years to recreate. The extent to which this can or will be attempted in an era of continuing pressure on DND resources is problematic. The problem is exacerbated by an ongoing hiring freeze and the fact that buyouts were particularly attractive to those recruited most recently. Thus, for several years, there has been essentially no new blood introduced into the system, a situation which is particularly damaging to an organization involved in serious research and development.

In addition to the impact on DND, the closure also inflicts a certain amount of collateral damage to other institutions. The viability of a number of small, local research companies, dependent on contracted R&D support, is questionable. Of perhaps greater long run importance will be the loss to universities. Over the years PNL/DREP provided immeasurable support and training to approximately five hundred summer students, many of whom have gone on to distinguished careers in teaching, research and industry—one, Tom Siddon, even becoming the Minister of National Defence.

Dr Prakash Bhartia, the Director General of DREA, presenting a retirement certificate to Bob Chapman for 42 years of service. Dr Bhartia was heavily involved in the formation and operation of EDRD until 13 February 1998 when he left DREA to become the Director General of DREO.

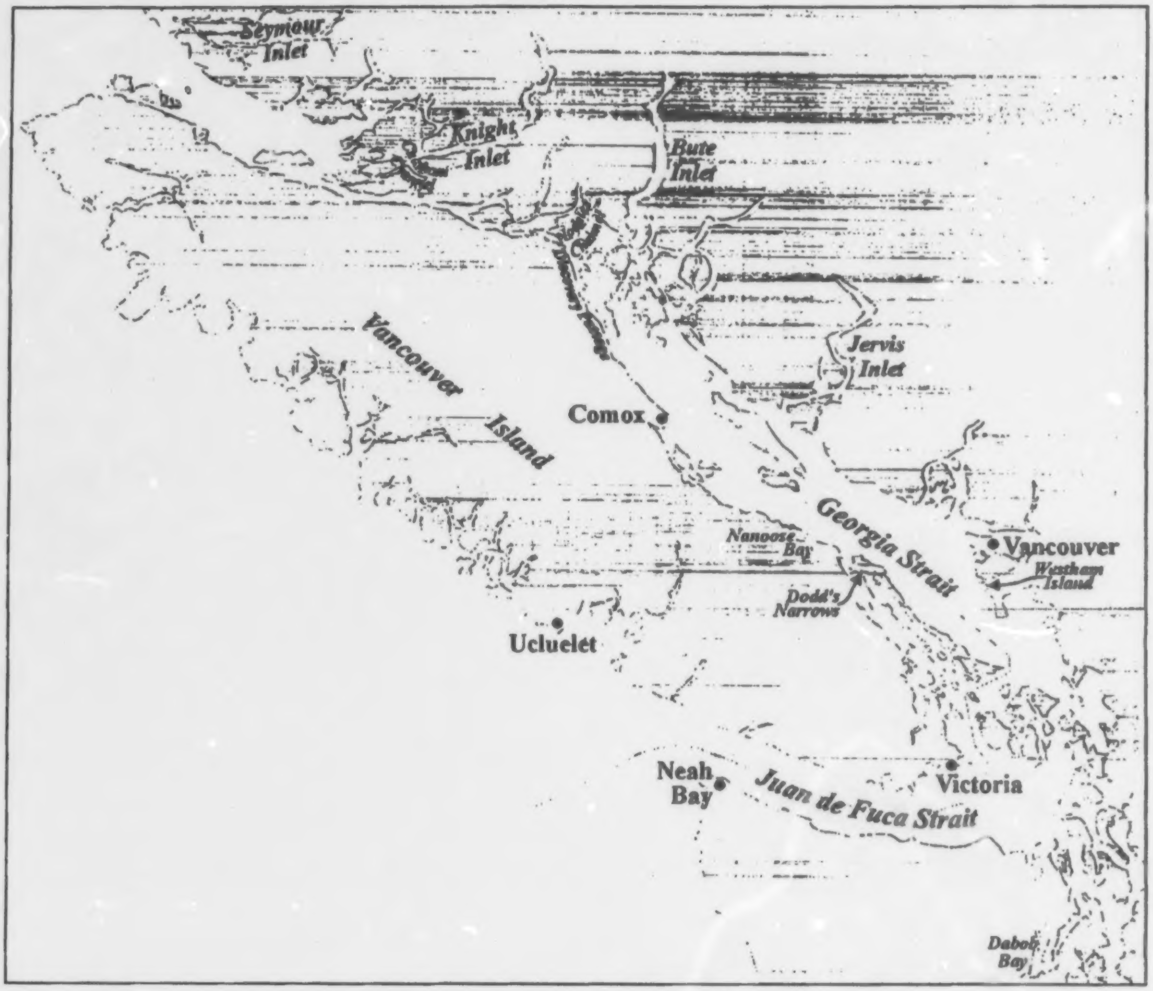


With the closing of DREP it became necessary to remove the crest which had graced the front entrance to building 199 for the preceding decade and a half. Ken Street, the recently appointed Director of EDRD, arranged for this to be conducted in style. A piper, Colin Murray, marches through the building to collect the staff for the closing ceremonies.

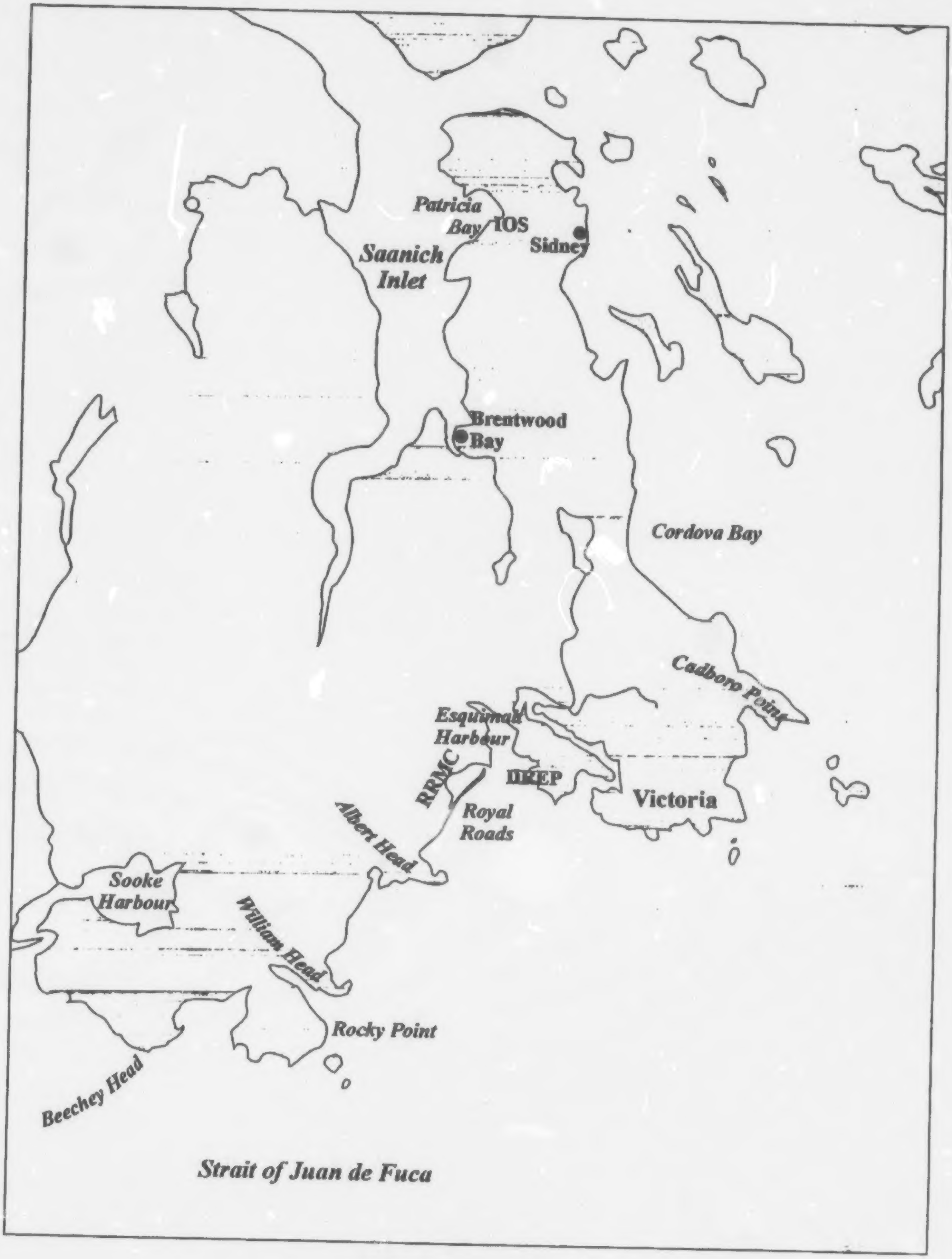
John Smith displays the removed DREP crest while Bob Chapman prepares to say a few words appropriate to the occasion.

MAPS

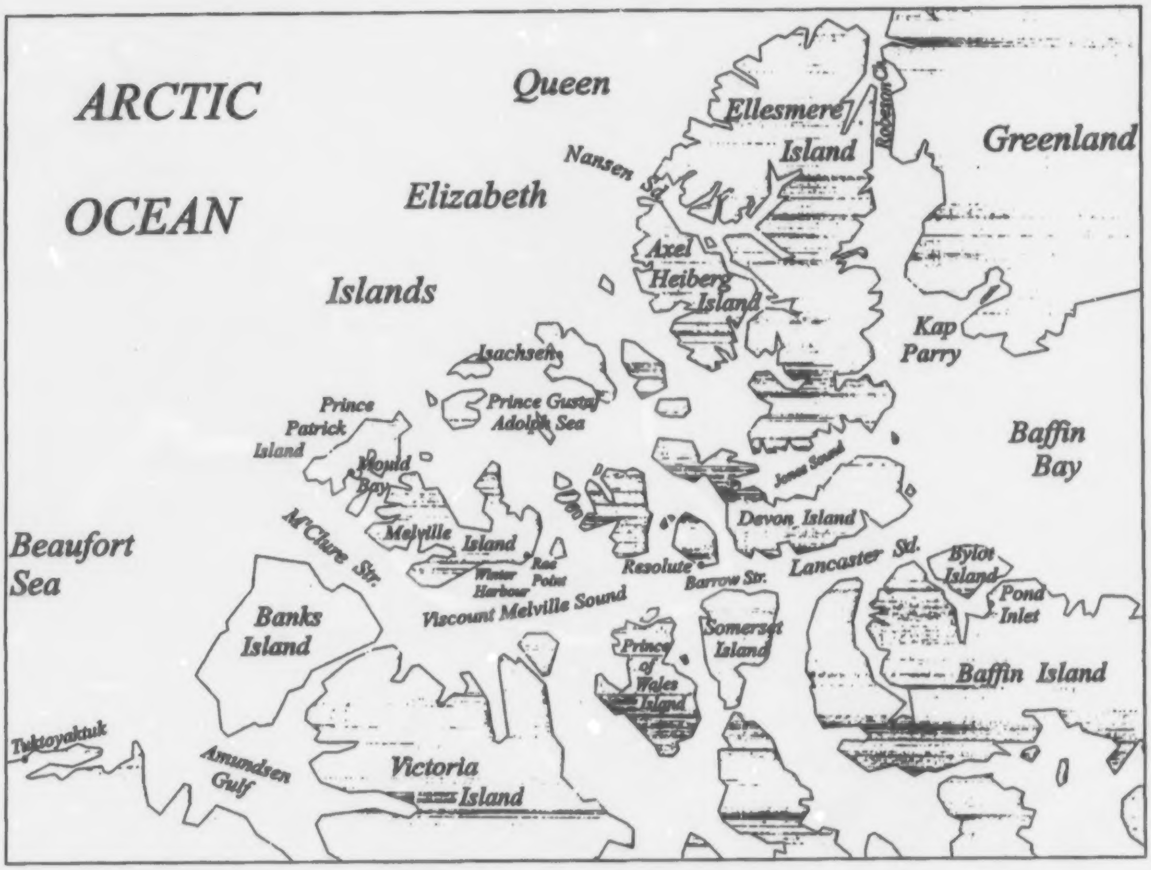
CFB ESQUIMALT and DREP — xx
Site of April'62 Can/US experiment 36
Seamounts and abyssal plains investigated acoustically 61
Location of *Paclabar* experiment 143
Location of *Icepack 1* 149
Location of *Icepack 2* 156
Arctic Ocean Sites in *Polarpack 1* 160
Location of *Icepack 4* 171
Location of *Icepack 5* 174
Locations of *Polarpack 2* and *3* 184
RIP sites 192
Initial location of sono-drift buoys 209
West Coast experimental sites 262
DREP and environs 263
Canadian Arctic Archipelago 264
South-Central Arctic 265
Northern Ellesmere Island 266



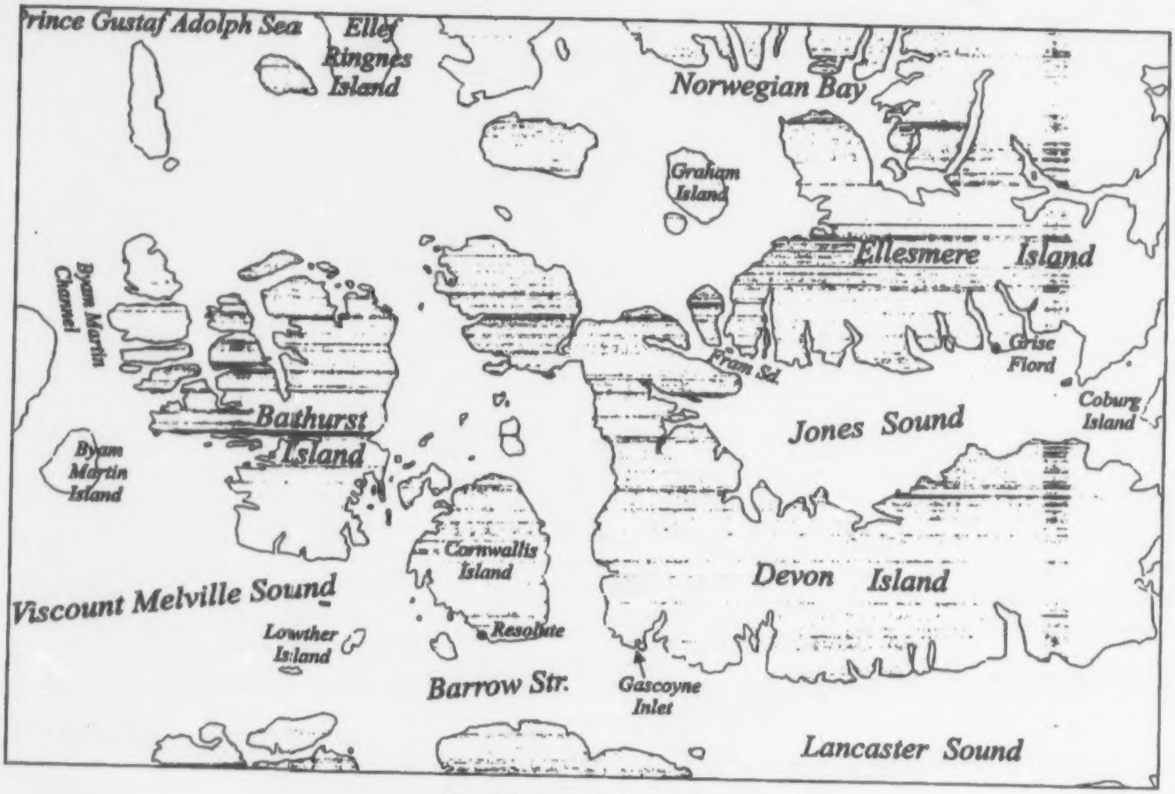
West Coast experimental sites



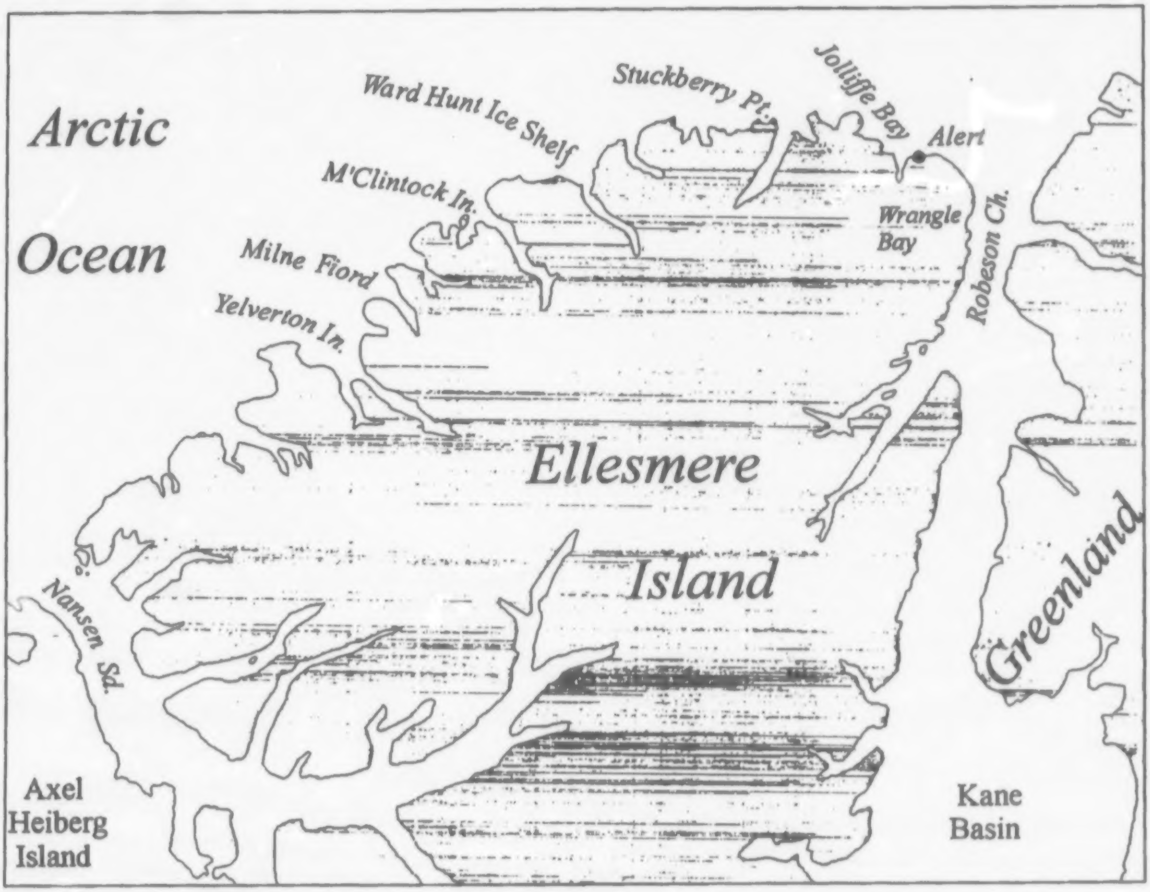
DREP and environs



Canadian Arctic Archipelago



South-Central Arctic



Northern Ellesmere Island

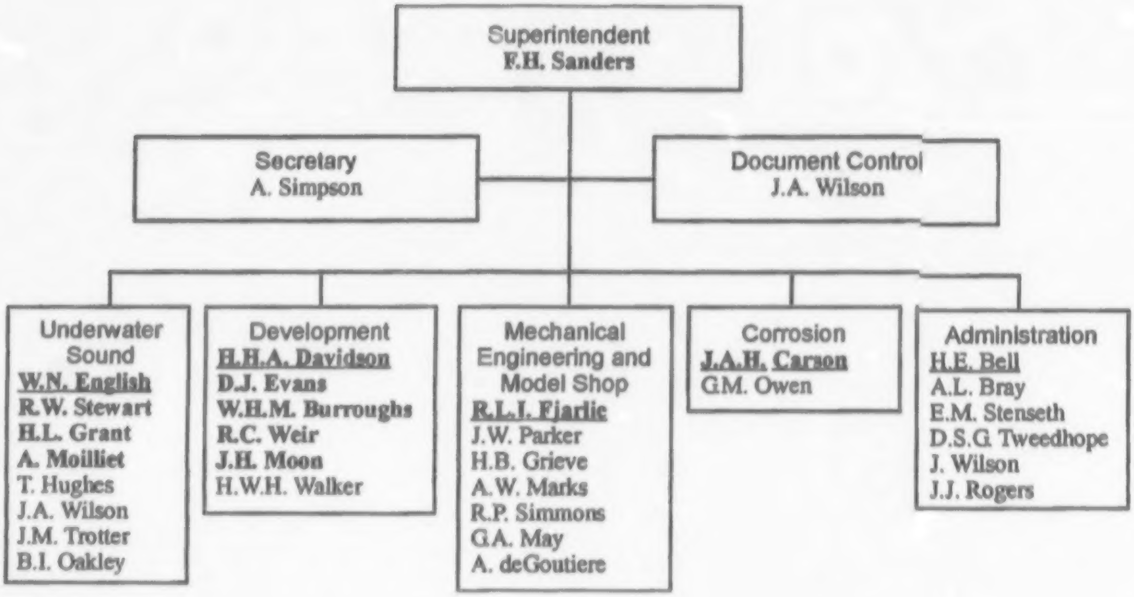
ORGANIZATION AND PERSONNEL

1951	Dr F.H. Sanders	268
1954	Mr J.S. Johnson	269
1958	Dr W.L. Ford	270
1966	Dr F.H. Sanders	271
1968	Mr R.F. Chinnick	272
1973	Dr J.T. Flynn	273
1980	Mr R.A. Kendall	274
1985	Dr H.L. Grant	275
1993	Dr T. Garrett	276

One organization chart is presented for each of the sections in Chapter 1. For the 1954 and 1958 charts no listings were available for the technical support and administrative staffs; for them it was necessary to tap the usually reliable memories of the staff working here at the time.

Professional staff and military officers are shown printed in **bold** and military of all ranks are shown in *italics.*

October 1951



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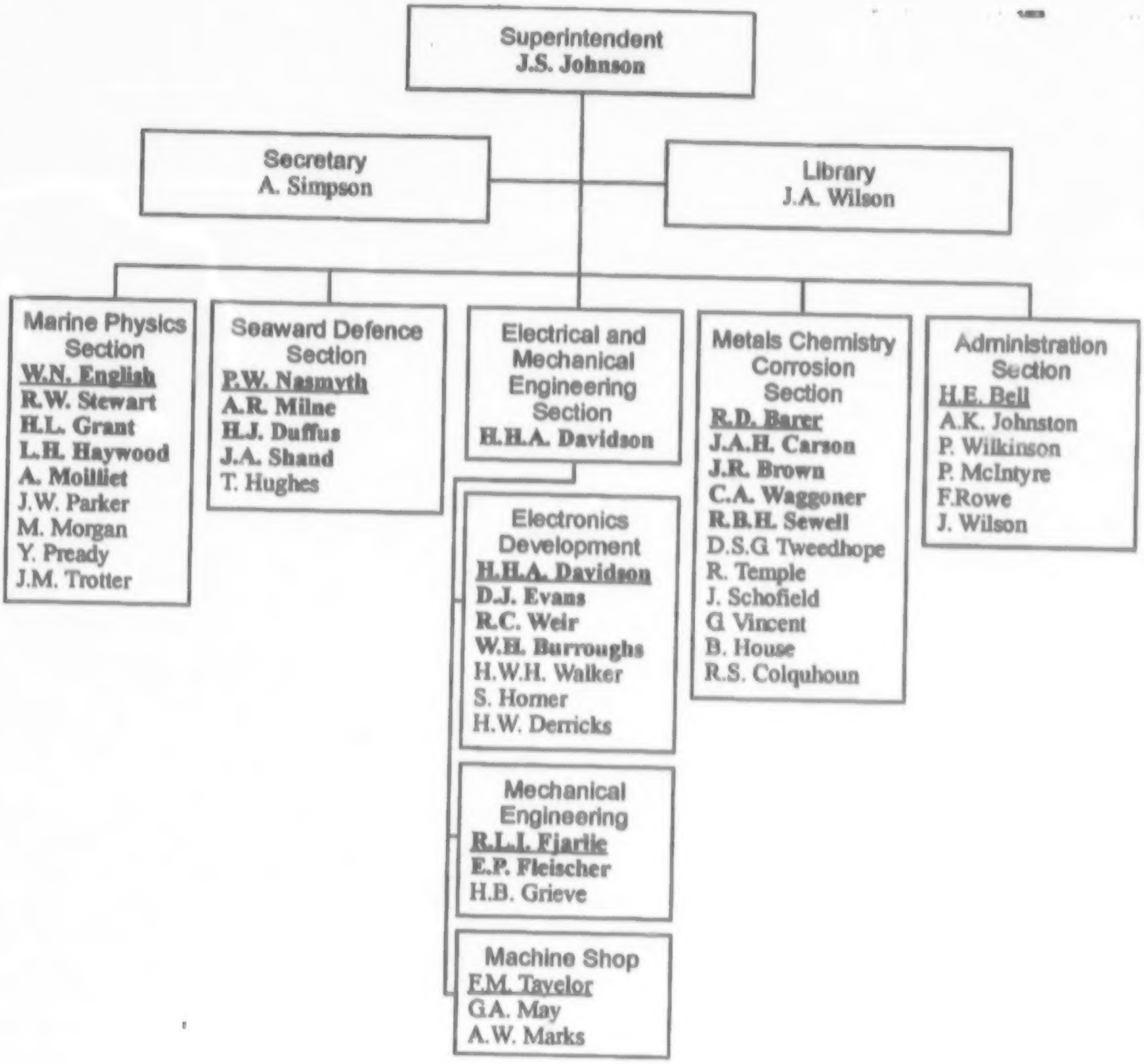

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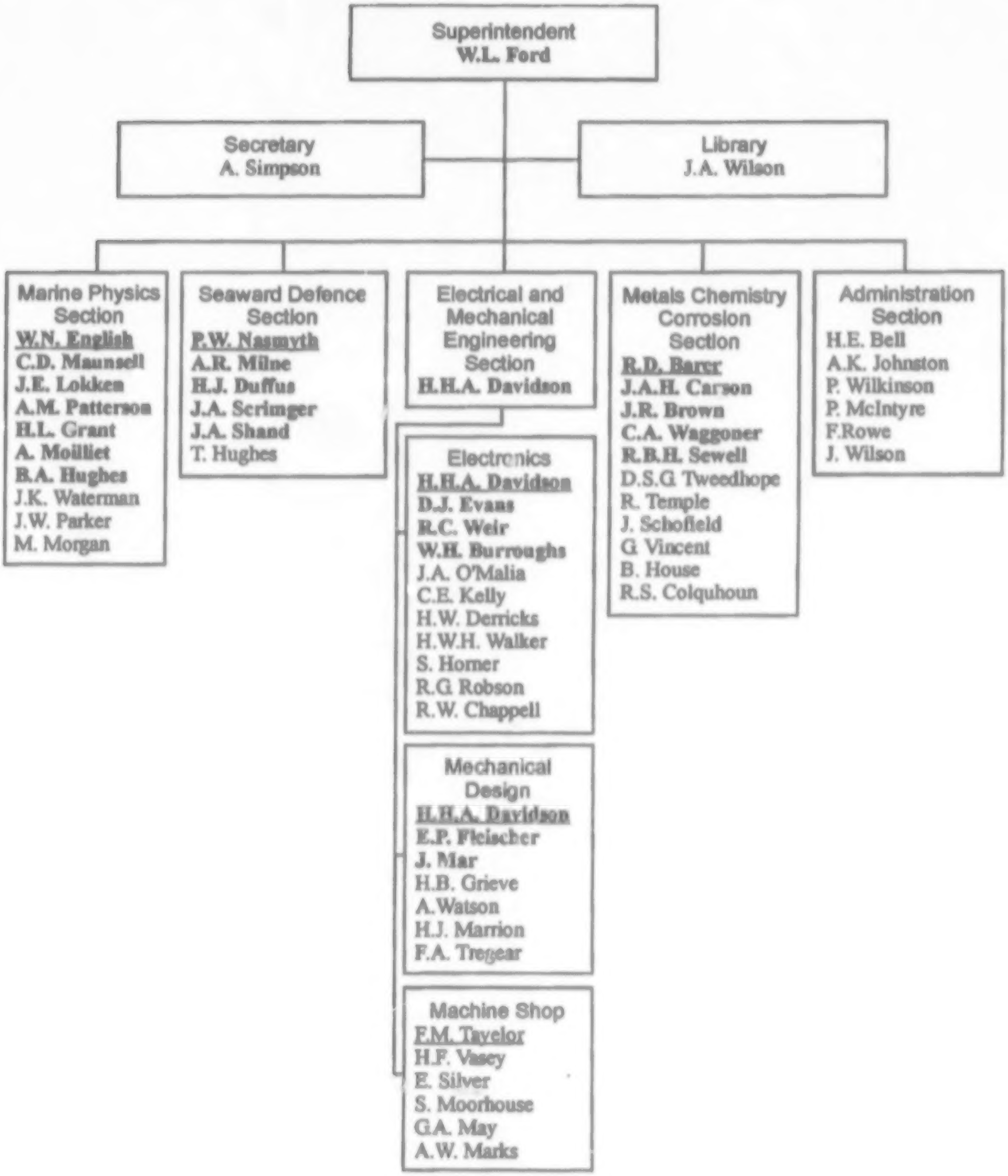
December 1958



Superintendent
W.L. Ford

Secretary
A. Simpson

Library
J.A. Wilson

Marine Physics Section
- **W.N. English**
- **C.D. Maunsell**
- **J.E. Lokken**
- **A.M. Patterson**
- **H.L. Grant**
- **A. Moilliet**
- **B.A. Hughes**
- J.K. Waterman
- J.W. Parker
- M. Morgan

Seaward Defence Section
- **P.W. Nasmyth**
- **A.R. Milne**
- **H.J. Duffus**
- **J.A. Scrimger**
- **J.A. Shand**
- T. Hughes

Electrical and Mechanical Engineering Section
- **H.H.A. Davidson**

Electronics
- **H.H.A. Davidson**
- **D.J. Evans**
- **R.C. Weir**
- **W.H. Burroughs**
- J.A. O'Malia
- C.E. Kelly
- H.W. Derricks
- H.W.H. Walker
- S. Horner
- R.G Robson
- R.W. Chappell

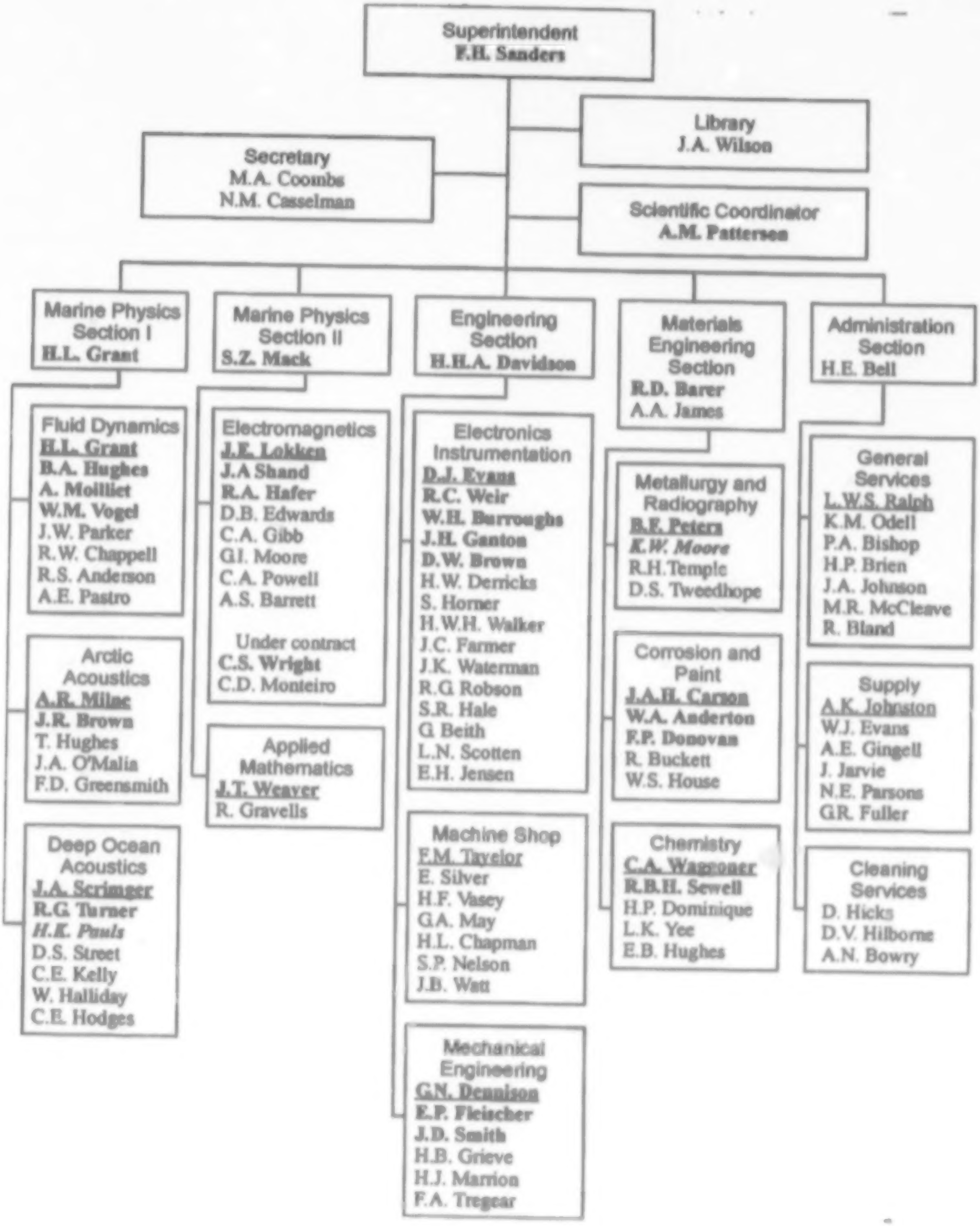
Mechanical Design
- **H.H.A. Davidson**
- **E.P. Fleischer**
- **J. Mar**
- H.B. Grieve
- A.Watson
- H.J. Marrion
- F.A. Tregear

Machine Shop
- F.M. Taylor
- H.F. Vasey
- E. Silver
- S. Moorhouse
- G.A. May
- A.W. Marks

Metals Chemistry Corrosion Section
- **R.D. Barer**
- **J.A.H. Carson**
- **J.R. Brown**
- **C.A. Waggoner**
- **R.B.H. Sewell**
- D.S.G Tweedhope
- R. Temple
- J. Schofield
- G Vincent
- B. House
- R.S. Colquhoun

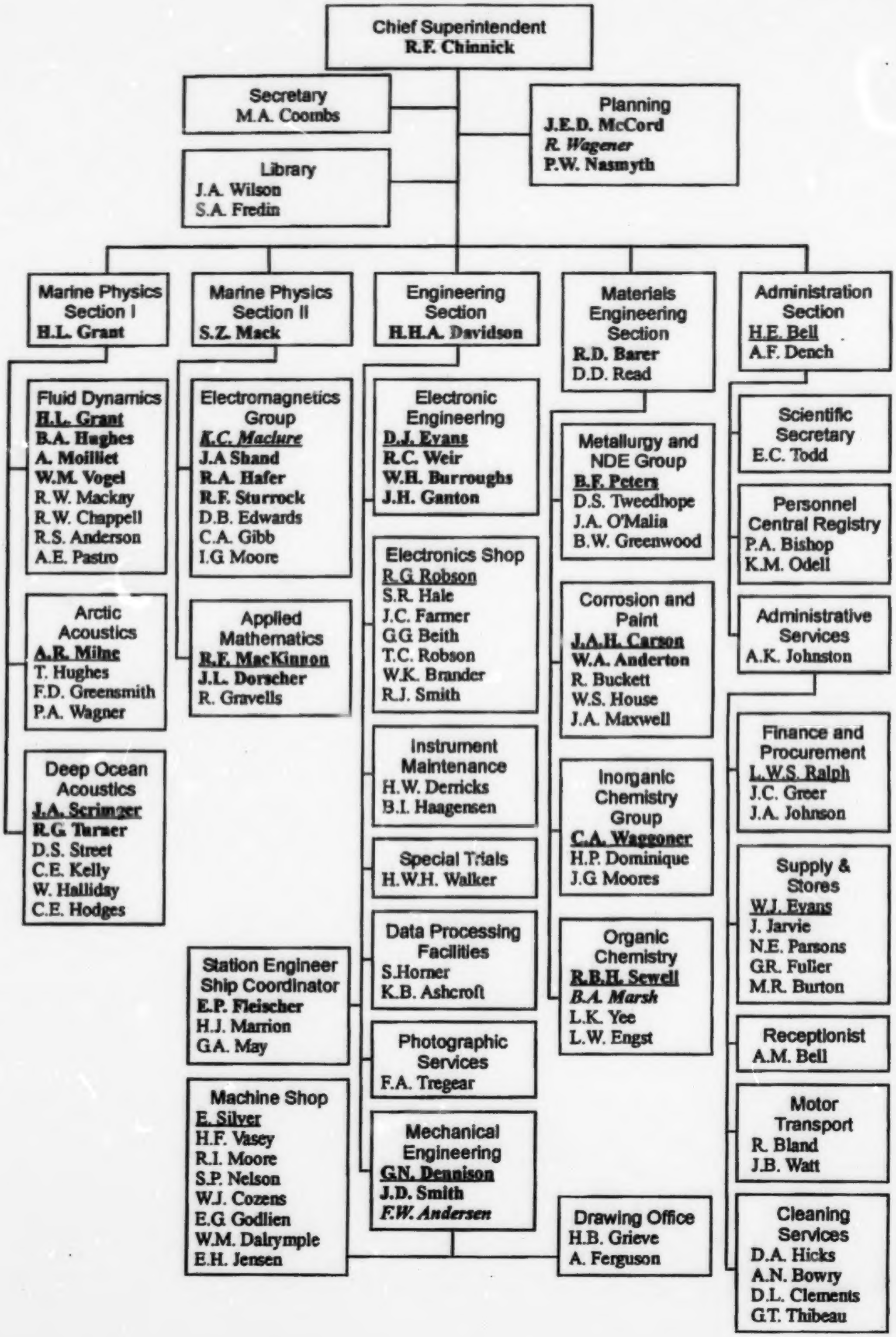
Administration Section
- H.E. Bell
- A.K. Johnston
- P. Wilkinson
- P. McIntyre
- F.Rowe
- J. Wilson

January 1966



- Superintendent **F.H. Sanders**
  - Library J.A. Wilson
  - Secretary M.A. Coombs, N.M. Casselman
  - Scientific Coordinator **A.M. Patterson**
  - Marine Physics Section I **H.L. Grant**
    - Fluid Dynamics: **H.L. Grant**, **B.A. Hughes**, **A. Moilliet**, **W.M. Vogel**, J.W. Parker, R.W. Chappell, R.S. Anderson, A.E. Pastro
    - Arctic Acoustics: **A.R. Milne**, **J.R. Brown**, T. Hughes, J.A. O'Malia, F.D. Greensmith
    - Deep Ocean Acoustics: **J.A. Scrimger**, **R.G. Turner**, ***H.K. Pauls***, D.S. Street, C.E. Kelly, W. Halliday, C.E. Hodges
  - Marine Physics Section II **S.Z. Mack**
    - Electromagnetics: **J.E. Lokken**, **J.A Shand**, **R.A. Hafer**, D.B. Edwards, C.A. Gibb, G.I. Moore, C.A. Powell, A.S. Barrett; Under contract: **C.S. Wright**, C.D. Monteiro
    - Applied Mathematics: **J.T. Weaver**, R. Gravells
  - Engineering Section **H.H.A. Davidson**
    - Electronics Instrumentation: **D.J. Evans**, **R.C. Weir**, **W.H. Burroughs**, **J.H. Ganton**, **D.W. Brown**, H.W. Derricks, S. Horner, H.W.H. Walker, J.C. Farmer, J.K. Waterman, R.G Robson, S.R. Hale, G Beith, L.N. Scotten, E.H. Jensen
    - Machine Shop: E.M. Taylor, E. Silver, H.F. Vasey, G.A. May, H.L. Chapman, S.P. Nelson, J.B. Watt
    - Mechanical Engineering: **G.N. Dennison**, **E.P. Fleischer**, **J.D. Smith**, H.B. Grieve, H.J. Marrion, F.A. Tregear
  - Materials Engineering Section **R.D. Barer**, A.A. James
    - Metallurgy and Radiography: **B.F. Peters**, ***K.W. Moore***, R.H.Temple, D.S. Tweedhope
    - Corrosion and Paint: **J.A.H. Carson**, **W.A. Anderton**, **F.P. Donovan**, R. Buckett, W.S. House
    - Chemistry: **C.A. Wagponer**, **R.B.H. Sewell**, H.P. Dominique, L.K. Yee, E.B. Hughes
  - Administration Section H.E. Bell
    - General Services: L.W.S. Ralph, K.M. Odell, P.A. Bishop, H.P. Brien, J.A. Johnson, M.R. McCleave, R. Bland
    - Supply: A.K. Johnston, W.J. Evans, A.E. Gingell, J. Jarvie, N.E. Parsons, G.R. Fuller
    - Cleaning Services: D. Hicks, D.V. Hilborne, A.N. Bowry

January 1968



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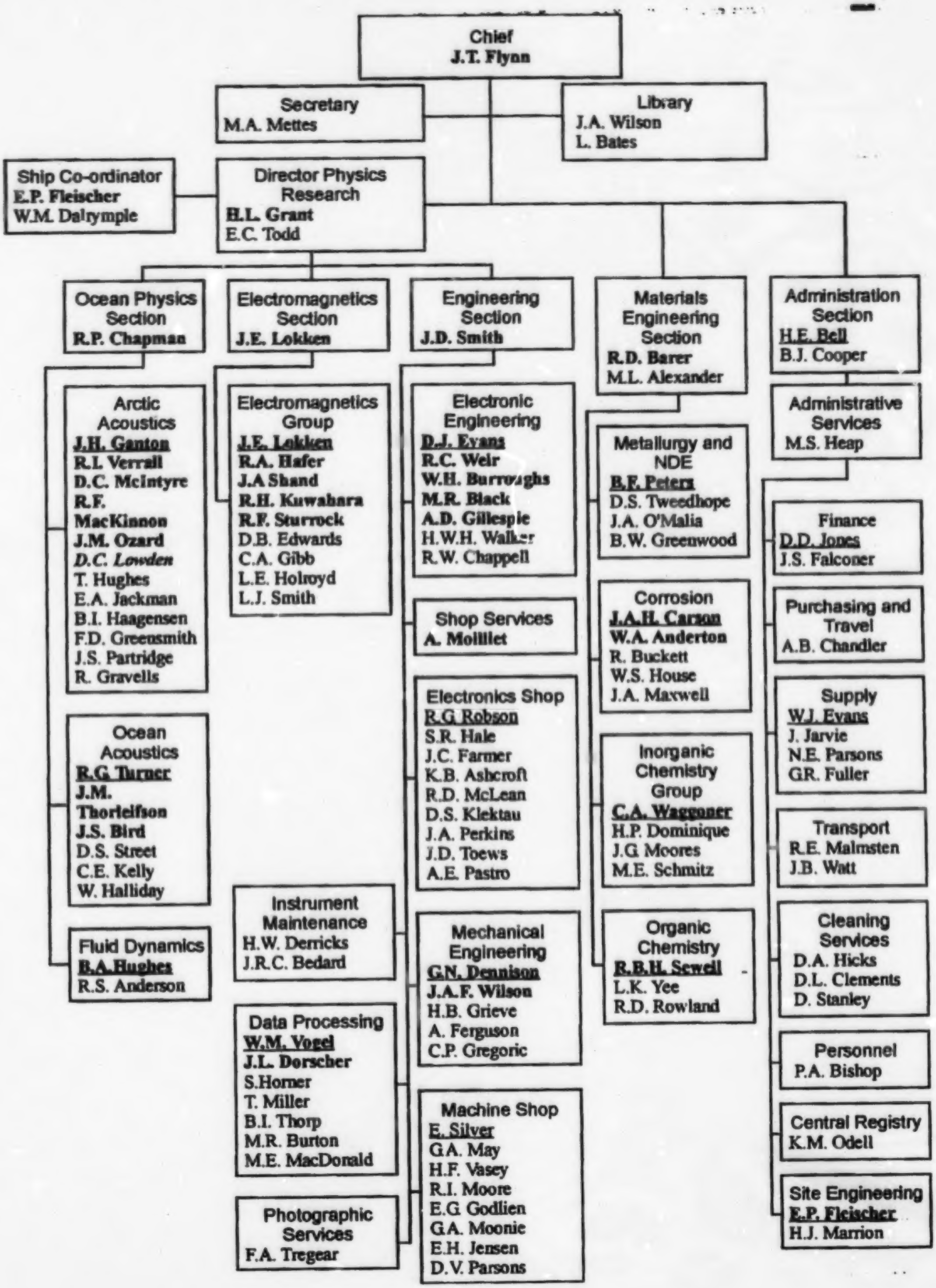
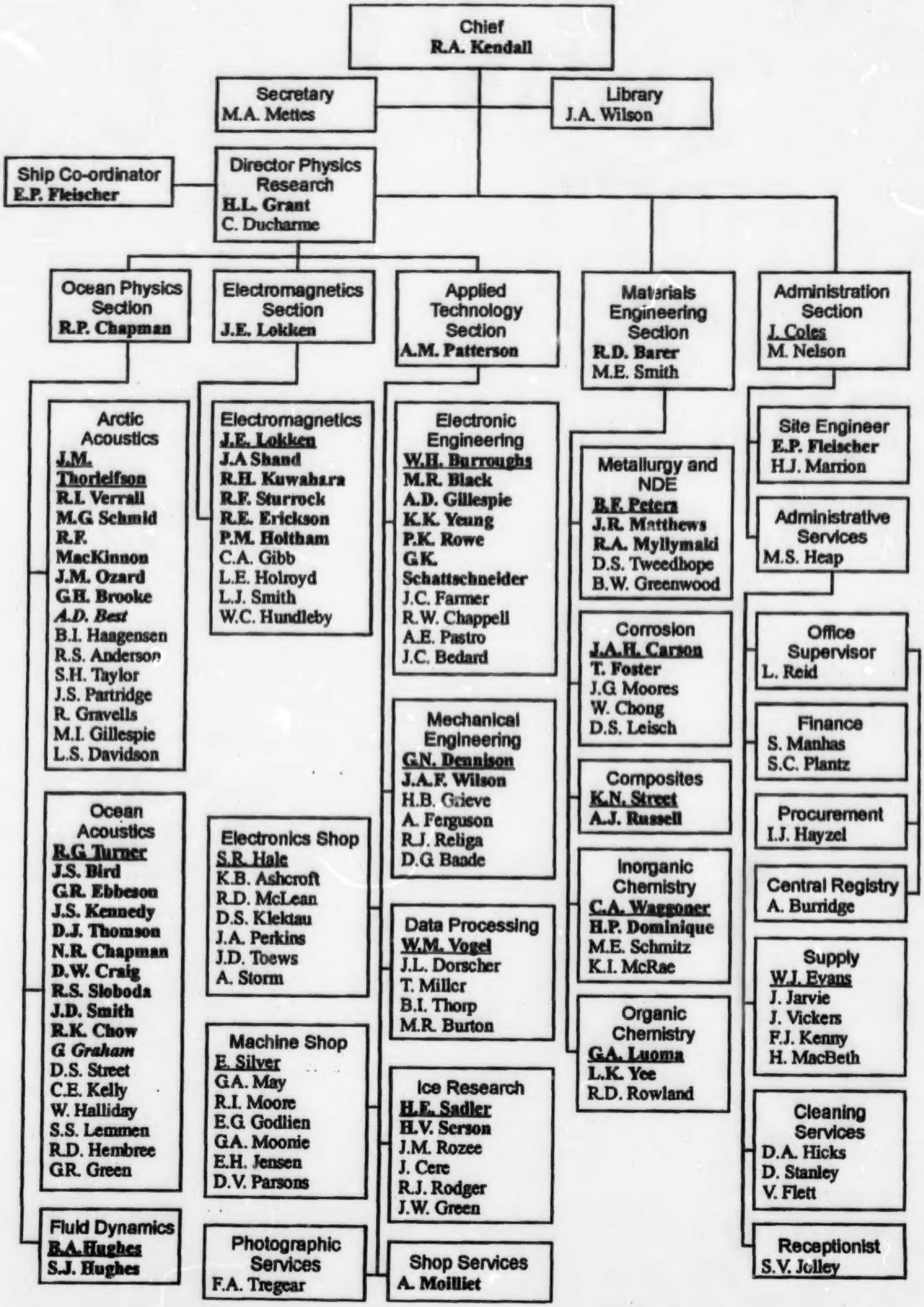
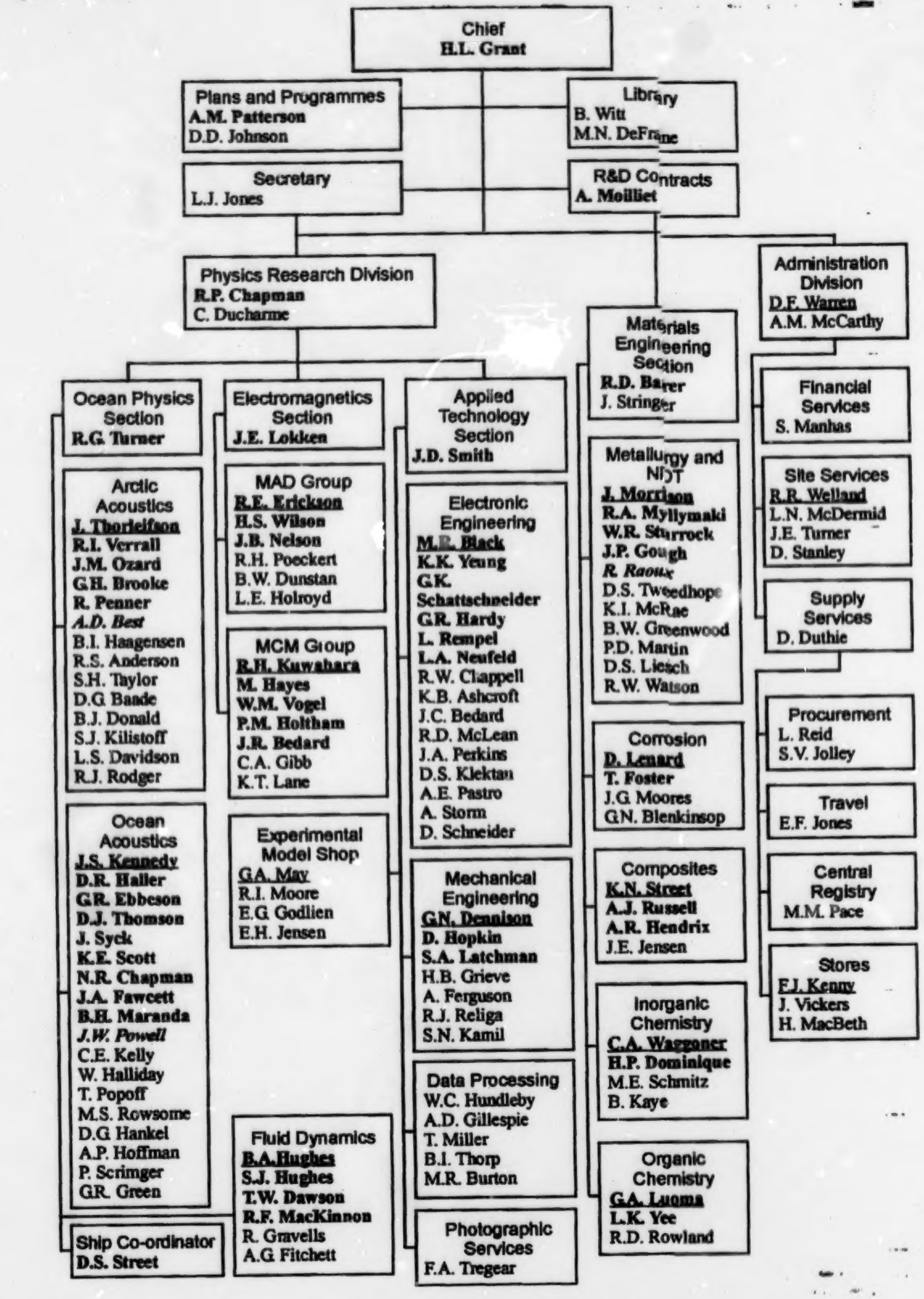


February 1980



- Chief
  R.A. Kendall
  - Secretary
    M.A. Mettes
  - Library
    J.A. Wilson
  - Director Physics Research
    H.L. Grant
    C. Ducharme
    - Ship Co-ordinator
      E.P. Fleischer
    - Ocean Physics Section
      R.P. Chapman
      - Arctic Acoustics
        J.M. Thorleifson
        R.I. Verrall
        M.G Schmid
        R.F. MacKinnon
        J.M. Ozard
        G.H. Brooke
        A.D. Best
        B.I. Haagensen
        R.S. Anderson
        S.H. Taylor
        J.S. Partridge
        R. Gravells
        M.I. Gillespie
        L.S. Davidson
      - Ocean Acoustics
        R.G Turner
        J.S. Bird
        G.R. Ebbeson
        J.S. Kennedy
        D.J. Thomson
        N.R. Chapman
        D.W. Craig
        R.S. Sloboda
        J.D. Smith
        R.K. Chow
        G Graham
        D.S. Street
        C.E. Kelly
        W. Halliday
        S.S. Lemmen
        R.D. Hembree
        G.R. Green
      - Fluid Dynamics
        B.A.Hughes
        S.J. Hughes
    - Electromagnetics Section
      J.E. Lokken
      - Electromagnetics
        J.E. Lokken
        J.A Shand
        R.H. Kuwahara
        R.F. Sturrock
        R.E. Erickson
        P.M. Holtham
        C.A. Gibb
        L.E. Holroyd
        L.J. Smith
        W.C. Hundleby
    - Applied Technology Section
      A.M. Patterson
      - Electronic Engineering
        W.H. Burroughs
        M.R. Black
        A.D. Gillespie
        K.K. Yeung
        P.K. Rowe
        G.K. Schattschneider
        J.C. Farmer
        R.W. Chappell
        A.E. Pastro
        J.C. Bedard
      - Mechanical Engineering
        G.N. Dennison
        J.A.F. Wilson
        H.B. Grieve
        A. Ferguson
        R.J. Religa
        D.G Baade
      - Data Processing
        W.M. Vogel
        J.L. Dorscher
        T. Miller
        B.I. Thorp
        M.R. Burton
      - Ice Research
        H.E. Sadler
        H.V. Serson
        J.M. Rozee
        J. Cere
        R.J. Rodger
        J.W. Green
      - Electronics Shop
        S.R. Hale
        K.B. Ashcroft
        R.D. McLean
        D.S. Klektau
        J.A. Perkins
        J.D. Toews
        A. Storm
      - Machine Shop
        E. Silver
        G.A. May
        R.I. Moore
        E.G Godlien
        G.A. Moonie
        E.H. Jensen
        D.V. Parsons
      - Photographic Services
        F.A. Tregear
      - Shop Services
        A. Moilliet
  - Materials Engineering Section
    R.D. Barer
    M.E. Smith
    - Metallurgy and NDE
      B.F. Peters
      J.R. Matthews
      R.A. Myllymaki
      D.S. Tweedhope
      B.W. Greenwood
    - Corrosion
      J.A.H. Carson
      T. Foster
      J.G Moores
      W. Chong
      D.S. Leisch
    - Composites
      K.N. Street
      A.J. Russell
    - Inorganic Chemistry
      C.A. Waggoner
      H.P. Dominique
      M.E. Schmitz
      K.I. McRae
    - Organic Chemistry
      G.A. Luoma
      L.K. Yee
      R.D. Rowland
  - Administration Section
    J. Coles
    M. Nelson
    - Site Engineer
      E.P. Fleischer
      H.J. Marrion
    - Administrative Services
      M.S. Heap
      - Office Supervisor
        L. Reid
        - Finance
          S. Manhas
          S.C. Plantz
        - Procurement
          I.J. Hayzel
        - Central Registry
          A. Burridge
      - Supply
        W.J. Evans
        J. Jarvie
        J. Vickers
        F.J. Kenny
        H. MacBeth
      - Cleaning Services
        D.A. Hicks
        D. Stanley
        V. Flett
      - Receptionist
        S.V. Jolley

April 1985



Chief
H.L. Grant

Plans and Programmes
A.M. Patterson
D.D. Johnson

Library
B. Witt
M.N. DeFrance

Secretary
L.J. Jones

R&D Contracts
A. Moilliet

Physics Research Division
R.P. Chapman
C. Ducharme

Ocean Physics Section
R.G. Turner

Arctic Acoustics
J. Thorleifson
R.I. Verrall
J.M. Ozard
G.H. Brooke
R. Penner
A.D. Best
B.I. Haagensen
R.S. Anderson
S.H. Taylor
D.G Bande
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S.J. Kilistoff
L.S. Davidson
R.J. Rodger

Ocean Acoustics
J.S. Kennedy
D.R. Haller
G.R. Ebbeson
D.J. Thomson
J. Syck
K.E. Scott
N.R. Chapman
J.A. Fawcett
B.H. Maranda
J.W. Powell
C.E. Kelly
W. Halliday
T. Popoff
M.S. Rowsome
D.G Hankel
A.P. Hoffman
P. Scrimger
G.R. Green

Ship Co-ordinator
D.S. Street

Electromagnetics Section
J.E. Lokken

MAD Group
R.E. Erickson
H.S. Wilson
J.B. Nelson
R.H. Poeckert
B.W. Dunstan
L.E. Holroyd

MCM Group
R.H. Kuwahara
M. Hayes
W.M. Vogel
P.M. Holtham
J.R. Bedard
C.A. Gibb
K.T. Lane

Experimental Model Shop
G.A. May
R.I. Moore
E.G Godlien
E.H. Jensen

Fluid Dynamics
B.A.Hughes
S.J. Hughes
T.W. Dawson
R.F. MacKinnon
R. Gravells
A.G Fitchett

Applied Technology Section
J.D. Smith

Electronic Engineering
M.R. Black
K.K. Yeung
G.K. Schattschneider
G.R. Hardy
L. Rempel
L.A. Neufeld
R.W. Chappell
K.B. Ashcroft
J.C. Bedard
R.D. McLean
J.A. Perkins
D.S. Klektau
A.E. Pastro
A. Storm
D. Schneider

Mechanical Engineering
G.N. Dennison
D. Hopkin
S.A. Latchman
H.B. Grieve
A. Ferguson
R.J. Religa
S.N. Kamil

Data Processing
W.C. Hundleby
A.D. Gillespie
T. Miller
B.I. Thorp
M.R. Burton

Photographic Services
F.A. Tregear

Materials Engineering Section
R.D. Barer
J. Stringer

Metallurgy and NDT
J. Morrison
R.A. Myllymaki
W.R. Sturrock
J.P. Gough
R. Raoux
D.S. Tweedhope
K.I. McRae
B.W. Greenwood
P.D. Martin
D.S. Liesch
R.W. Watson

Corrosion
D. Lenard
T. Foster
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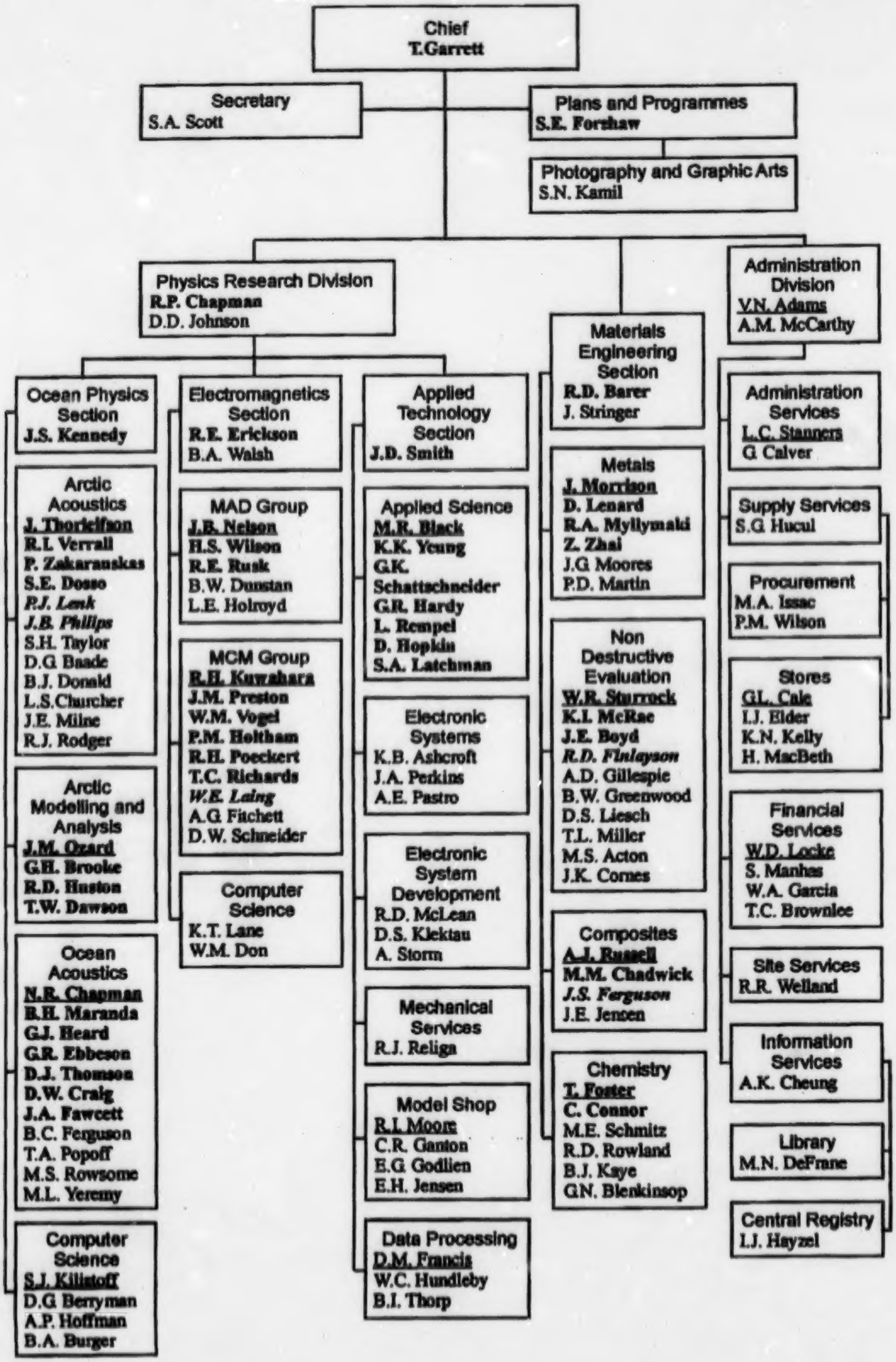

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ACRONYMS

ADM(Mat)	Assistant Deputy Minister (Material)
AGARD	Advisory Group in Aircraft Research and Development
AIMS	Automated Integrated Magnetic Anomaly Detection System
AOR	Auxiliary Oiler Replenisher
APL	Applied Physics Laboratory University of Washington – Seattle, WA
ARCS	Autonomous Remote Controlled Submersible
ARE	Admiralty Research Establishment (formerly AUWE) – Portland, UK
ARL	Arctic Research Laboratory – Barrow, Alaska
ASM	American Society of Metals
ASTM	American Society for Testing Materials
ASW	Anti-submarine Warfare
ATF	Advanced Tactical Fighter
AUV	Autonomous Underwater Vehicle
AUWE	Admiralty Underwater Weapons Establishment – Portland, UK
AWRE	Atomic Weapons Research Establishment – Aldermaston, UK
BCS	Barrodale Computing Services – Victoria, BC
BIO	Bedford Institute of Oceanography – Dartmouth, NS
CANAPES	Canadian Acoustic Parabolic Equation System
CANARPS	Canadian Acoustic Range Prediction System
CANTASS	Canadian Towed Array Sonar System
CARDE	Canadian Armament Research and Development Establishment (later DREV) – Valcartier, PQ
CASI	Canadian Aeronautics and Space Institute
CBDA	Clearance Breathing and Diving Apparatus
CDC	Computing Devices of Canada – Ottawa, ON
CEOR	Centre for Earth and Ocean Research – UVic, Victoria, BC
CF	Canadian Forces
CFAV	Canadian Forces Auxillary Vessel
CFB	Canadian Forces Base
CFMETR	Canadian Forces Maritime Experimental and Test Ranges – Nanoose, BC
CFS	Canadian Forces Station
CGSB	Canadian Government Specification Board
CIC	Chemical Institute of Canada
CNAV	Canadian Navy Auxillary Vessel
COAMS	Canadian Ocean Acoustic Measurement System
CPF	Canadian Patrol Frigate
CRAD	Chief of Research and Development
CSCS	Canadian SURTASS Concepts Study
CTF	Canadian Thin Films Inc – Port Coquitlam, BC
DARPA	Defence Advanced Research Projects Agency

DDE	Destroyer Escort
DDH	Destroyer Helicopter
DEMR	Department of Energy Mines and Resources
DMOR	Director Maritime Operations Research
DM&TS	Department of Mines and Technical Surveys
DND	Department of National Defence
DOT	Department of Transport
DRB	Defence Research Board
DREA	Defence Research Establishment Atlantic – Dartmouth, NS
DREO	Defence Research Establishment Ottawa – Ottawa, ON
DREP	Defence Research Establishment Pacific – Esquimalt, BC
DRES	Defence Research Establishment Suffield – Suffield, AB
DREV	Defence Research Establishment Valcartier – Valcartier, PQ
DRNL	Defence Research Northern Laboratory – Churchill, MB
DSS(N)	Director Scientific Services, Navy – NDHQ, Ottawa, ON
DTMB	David Taylor Model Basin – Washington, DC
EDRD	Esquimalt Defence Research Detachment, Victoria, BC
EER	Explosive Echo-Ranging
EHM	Engine Health Monitoring
ELF	Extremely Low Frequency
ELFE	Extremely Low-Frequency Effects
EMR	Energy Mines and Resources
EPI	Establishment of Primary Interest
ERIM	Environmental Research Institute of Michigan
FACS	Fully Automated Compensation System
FDA	Filter Debris Analysis
FDU(P)	Fleet Diving Unit Pacific – CFB ESQUIMALT, Victoria, BC
FRB	Fisheries Research Board
GTP	TTCP Subgroup G Technical Panel, (Undersea Warfare)
HIFT	Heard Island Feasibility Trial
HOTEF	Helicopter Operational Test and Evaluation Facility
IAR	Institute of Aerospace Research – Ottawa, ON
IHL	International Hydrodynamics Limited – Vancouver, BC
IOS	Institute of Ocean Sciences – Patricia Bay, BC
IOUBC	Institute of Oceanography at UBC – Vancouver, BC
ISE	International Submarine Engineering – Port Coquitlam, BC
ISER	International Submarine Engineering Research – Port Coquitlam, BC
ISSC	International Ship Structures Committee
ITASS	Interim Towed Array Sonar System
JOWIP	Joint CAN/US Ocean Wave Investigation Project
LRPA	Long Range Patrol Aircraft
MAD	Magnetic Anomaly Detection
MADSIM	MAD Simulation
MAG	Maritime Air Group
MARPAC	Maritime Command Pacific
MCDV	Maritime Coastal Defence Vessel

MCM	Mine Countermeasures
MDA	MacDonald Detwiler and Associates, Vancouver, BC
MEVA	Multi-Element Volume Array
MFP	Matched Field Processing
MILSPEC	Military Specification
MOT	Ministry of Transport
MP&EU	Maritime Proving and Evaluation Unit
MPL	Marine Physics Laboratory – at Scripps, San Diego, CA
MTS	Materials Testing System
NACE	National Association of Corrosion Engineers
NADC	Naval Air Development Center – Warminster, PA
NAE	National Aeronautical Establishment – Ottawa, ON
NASA	National Aeronautics and Space Administration
NAVSEASYSCOM	Naval Sea Systems Command
NDC	National Defence College – Toronto, ON
NDE	Nondestructive Evaluation
NDHQ	National Defence Headquarters – Ottawa, ON
NDT	Nondestructive Testing
NOL	Naval Ordnance Laboratory – Silver Spring, MD
NORDA	Naval Ocean Research and Development Activity – Bay Saint Louis, MS
NORPAC	North Pacific oceanographic survey
NORPLOY	Northern Deployment
NOSC	Naval Ocean Systems Center – San Diego, CA
NRaD	Naval Command and Control and Ocean Surveillance Center (NCCOSC)Research and Development – San Diego, CA
NRC	National Research Council
NRE	Naval Research Establishment – Halifax/Dartmouth, NS
NRL	Naval Research Laboratory – Washington, DC
NUC	Naval Undersea Center – San Diego, CA
ONR	Office of Naval Research – Washington, DC
OPI	Office of Primary Interest
OPVAL	Operational Evaluation
OSL	Offshore Surveys Ltd – Vancouver, BC
OSRMS	Ocean Surface Roughness Measurement System
PAG	TTCP Subgroup P Action Group
PCSP	Polar Continental Shelf Project
PE	Parabolic Equation
PINS	Precision Integrated Navigation System
PMAP	Polar Margin Aeromagnetic Program
PNL	Pacific Naval Laboratory – Esquimalt, BC
POG	Pacific Oceanographic Group – Nanaimo, BC
PTP	TTCP Subgroup P Technical Panel, (Materials Research)
RCMHS	Remotely Controlled Minehunting System
RIP	Recording Instrument Package
RMC	Royal Military College – Kingston, ON
RNSS	Royal Navy Scientific Service – London, UK

ROV	**Remotely Operated Vehicle**
RRMC	**Royal Roads Military College – Victoria, BC**
SACLANTCEN	**SACLANT Research Center – Laspezia, Italy**
SAR	**Synthetic Aperture Radar**
SARSAT	**Search and Rescue Satellite**
SARSEX	**Synthetic Aperture Radar Signature Experiment**
SCC	**Stress Corrosion Cracking**
SDL	**Submersible – Diver Lockout**
SES	**Suffield Experimental Station – Suffield, AB**
SIO	**Scripps Institute of Oceanography – San Diego, CA**
SIPS	**Sonar Image Processing System**
SNNR	**Senior National Naval Representatives**
SOA	**Spectrographic Oil Analysis**
SOAP	**Spectrometric Oil Analysis Program**
SPUD	**Signal Processing Ultrasonic Device**
SQUID	**Superconducting Quantum Interference Device**
STI	**Space-Time Integration**
SURSAT	**Surveillance Satellite**
SURTASS	**Surveillance Towed Array Sonar System**
SUS	**Signal Underwater Sound**
TACTASS	**Tactical Towed Array Sonar System**
TESPEX	**TTCP Environmental Signal Processing Experiment**
TMA	**Target Motion Analysis**
TSRV	**Torpedo and Ship Ranging Vessel**
TTCP	**The Technical Cooperation Program**
UBC	**University of British Columbia – Vancouver, BC**
UBIS	**Ultrasonic Boiler Inspection System**
UCLA	**University of California at Los Angeles**
USCC	**Undersea Surveillance Co-ordinating Committee**
USNEL	**US Navy Electronics Laboratory – San Diego, CA**
USNUSL	**US Navy Underwater Sound Laboratory – New London, CT**
UVic	**University of Victoria – Victoria, BC**
VDS	**Variable Depth Sonar**
VLA	**Vertical Line Array**
WRAP	**Wide-area Rapid Prediction computer program**

INDEX

(Page numbers for individuals identified in photographs are in italics)

A

Acton, Murray S., 248
Adams, Victoria N., *102*
Anderson, Marilyn A., *102*
Anderson, Richard S., 212-3, *225*, 229
Anderton, W. Arthur, 237, 239
Ashcroft, Kenneth B., *131*

B

Baade, David G., 81, 88, *111*, 114
Baker, Benjamin, *78*
Barer, Ralph D., 7, 12, 17, *44*, 83, *100*, 101, 140, 212, 237-8, *242*, 244-9
Beale, Dr Alan, 160, 184
Beath, George, 181
Bell, Harry E., *3, 9, 239*
Berger, David G., 114
Berryman, Donald G., 236
Bhartia, Dr Prakash, *259*
Bird, Dr John S., 15
Black, Mervyn R., 109, 114, 248
Blais, Hon Jean-Jacques, *84*
Blenkinsop, Geoffrey N., 252
Blommers, John, 230
Bobyn, Edward J., *57-8, 78, 85*
Bonewits, Cdr Donald, 185, 187
Bowers, Capt Christopher P., 248, 251
Bowles, Captain Stanley, *57-8*
Boyd, Jeffrey E., 15, 248
Brooke, Dr Gary H., 88, 113
Brown, J. Raymond, 17, 35-6, *100*, 167, 171, 178-9, 182-3, 237, 239
Brown, David W.,178-9
Browning, David G., 107
Brownlee, T. Chris, *102*
Brownlee, Dr W. Grant, *78*
Buckett, Raymond, 237, 239, *240*, 242
Burroughs, William H., 156, 158, 180, 184, *185*, 191-2, *195*

C

Calver, Geraldine, *102*
Cameron, Dr William R., 10-11, 15
Carson, John A.H., 7, 75-6, 83, 213, 237, *239*, 240-1, 244-5, 247
Cassidy, Captain, 215
Chadwick, Dr Margaret M., 254
Chapman, Dr N. Ross, 62, 87, 103, 105, 107-8
Chapman, Dr Robert P., 59, 84, *99-100, 104, 259-60*
Chappell, Robert W., 63, *86*, *126*, *131*, 212, 215, 217, 220-1, *225*, 227-230, 235, 242
Chinnick, Robert F., 46-7, *48*, 55
Churcher, Linda S., 114
Clark, F. Gordon, *100*
Claxton, Hon Brooke, *7*
Connor, Dr Charles, 254
Coote, Robert, 247
Cornes, John K., 248, 250
Craig, Dr David W., 15, 103
Crean, Dr Patrick, 178, 182, *183*, 184-5, 188-9, *190*
Croal, Cdr James, 143, 148, 173
Cuthbert, Captain, 172

D

Davidson, Harry H.A., 3, 8, *9*, 59, 156, 212-3
Davies, LCdr Tudor C., 109, 114, *117*
Dawson, Dr Trevor W., 113, 232, *234*, 235-6
Dennison, Graeme N., 149, 161, 191, 212, 216, 219, 227
Derricks, Hugh W., 212
Dodd, Gary, 237
Dominique, Harry P., 139, 237, *243*
Don, Wendy M., *131*
Donald, Brendan J., 114
Dosso, Dr Harry W., 43
Dosso, Dr Stanley E., 113
Dougherty, D., *78*
Douglas-Home, Sir Alec, *29*
Duffus, Dr H. John, 17, *25-6*, 27
Duncan, Terry, *102*
Dunstan, Brian W., 123-4
Dunwoody, Dr Bruce, *80*

E

Ebbeson, Gordon R., 61, 114
Edmonds, Mim, 7
Edwards, David B., 212
Elder, Ian J., *102*
Elliot, Dr Joseph, 229
English, Dr William N., 6, 27, *29*, 31, 142, 150, 153
Engst, Lenard, 237
Erickson, Roy E., 71, 92, *100*, 123, *131*
Evans, Donald J., 27, *39*, 40, 212-3, 240

F

Fabula, Dr Andrew, 213, 217
Fassold, Col Robert, *78*
Fawcett, Dr John A., 107, 236
Fedorak, William, 145
Ferguson, Capt J. Scott, 248
Fergusson, Fergus A.A., *78*
Field, Gene, *102*
Finlayson, Maj Rick D., 248
Fitchett, Arthur G., *131*, 231, *234*, 235
Fleischer, Edwin P., *140*, 171, 184, 191
Fleming, Douglas, 102
Flynn, Dr James T., 55, *56-7*, 77-8
Ford, Dr William L., 18, *19*, 27, *28-30, 56*
Foster, Dr Terry, 83, 241, 248-50, 254-6
Foxall, Thomas, 123-4
Franks, James, 237
Fraser, A., *78*

G

Gain, Donald, 175

Ganton, Colin R., 114
Ganton, John H., 59, 167, 170, 174, *175*, *177*, 180-1, 183, 188, 191-3, 196, 204, *206*, 207-9
Garcia, William A., *102*
Garland, Maj Kevin, *78*
Garrett, Dr Todd, 99, *100*, *103*, *136*
Geldart, Dr Lloyd P., 42
Gibb, Chistopher A., 39
Gillespie, Alan D., *234*, 235, 248
Gower, Dr James F.R., 230
Grant, Dr Harold L., *5*, 15, 17, 23, *28*, 31, *51*, 59, 83, *84*, 99, 174, 212-3, *218*, *225*, 228-9, *236*
Gravells, Roy, 229, 235
Gray, Matt, *242*
Greensmith, Frank D., 167
Greenwood, Barry W., 243-4, *247*, 248, 252, 256
Gwalchmai, LCdr Robert F., 127

H

Hafer, Rodney A., 59
Haagensen, Borg I., 205
Hale, S. Raymond, 39, *169*, 182, *183*
Hall, Cdr, *19*
Haller, Dennis R., 87
Hammond, Raymond, 198, 200
Hardy, T., *30*
Hare, Capt Gary, 114
Harkness, Hon Douglas, *37*
Harwood, Trevor, 142-5, *144*, 148, 160, 177
Hase, LCdr Charles, 237
Hayes, Dr Michael, 94
Heard, Dr Garry J., 83, 108
Heggie, Dr Robert M., *78*
Hendrix, Arleen R., 248
Herlinveaux, Richard, 141, 150, 155, 161, 164, *177*, 182, 192, *193*, 197, 199
Hersey, Dr J. Brackett, 141
Hewitt, LCdr James, 129
Hibbard, Admiral J.C., *13*
Hollister, Dr Harry, 171
Holtham, Dr Peter M., 125, 133, *135*
Hopkin, David, 15, 109, 114, *120*, 124, *131*, 256
House, William S., 237
Hucyl, Sidney G., *102*
Hughes, Dr Blyth A, 15, *23*, *30*, 52, 70, 82, 91, 101, 212-3, 222, *225*, 227, 229-32, 235, *236*
Hughes, Steven J., 232, *234*, 235
Hughes, Thomas, 141, 143, *144*, 148, 150, 156, 158, 161, *163-4*, 167, 171, 175, 178, 182, 184, *185*, 188, *190*, 196-7, 205, 208
Hunt, Frank, 182, 205

I

Issac, Myrna A., *102*
Iverson, Clay R., *78*

J

Jackoosie, 144-8
Jacobs, Dr J.A., 42
Jarvie, James, *30*
Jensen, J. Ernest, 98, 248
Jensen, Captain E., 78
Johnson, J. Stewart, 12, *13*, 18
Jones, Rt Hon Aubrey, *30*
Jones, Eloise F., *102*

K

KarisAllen, Kenneth J., 248, 252
Karkut, Maj Edward T., 248
Kaye, Bruce J., 250, 252, 256
Kelly, Carl E., 143, *144*, *147*, 150, *155*, 182
Kelly, Kenneth N., *102*
Kendall, Richard A., 77, *78*, 83
Kennedy, James S., 84, 87, 103, 114, *119*
Kenny, Frank J., *102*
Kerstin, Laurie, *102*
Kilistoff, Steven J., 114
Kutschale, Dr Henry, 160
Kuwahara, Dr Ronald H., 84, 95, 125, 129, *131*

L

Labrie, Albert, *131*
Laing, LCdr William E., 127
Lane, Kurt T., *131*
Langlieben, Dr M. Phillip, 150, 154-5
LeGallais, LCdr Paul S., 127
Lenard, Dr Derek, 83, 239, 252, 254, *255*
Lenk, LCdr Peter J., 114
L'Heureux, Dr J. Leon, *75*
Liesch, Daniel S., 252, 256
Locke, Wayne D., *102*
Lokken, Dr J. Erwin, 16, 39, 59, 79
Lucking, Dr W. Michael, 248
Luoma, Dr Gregory A., 98, 137, 139, 249, *250*, 251-2
Lyon, Dr Waldo K., 160

M

MacBeth, Helen, *102*
MacDermid, Larry N., *102*
MacDonald, John, 197, 200, 202
MacDonald, Mark, 248
Mack, Dr Stanley Z., 31
MacKinnon, Dr Robert F., 236
MacMillan, Laurie, *102*
MacRay, Maj Allen G., 248
Maggay, LCdr Isadoro, 184-5
Mainguy, Adm E.R., *13*
Manhas, Shanti, *102*
Maranda, Brian H., 106
Mar, John, 100
Marsh, Capt Brent, 237
Marsh, Dr H. Wyser, 160
Martin, Lin, 39
Martin, Paul D., 252, 256
Matthews, Dr James R., 76, 247-8
Maunsell, Dr Charles D., 16
Maxwell, James A., 247
McCarthy, Allie May, *102*
McClure, G/C Kenneth, *48*
McKenzie, Alison, 252, 256
McMunagle, Capt William, 232
McRae, Kenneth I., 15, 248-50, *251*, 252
Meakin, Lt Michael, 127, *131*
Mellen, Dr Robert H., 160
Miller, Terance L., *131*, 248, 252
Milne, Allen R., 16-17, 35, 59, 141-210, *144*, *146*, *155*, *159*, *163*, *180*, *187*, *190*
Milne, James E., 114, *120*
Moilliet, Antony, *23*, *46*, 60, 212-4, *218*, *225*, 229-30, *236*, 256
Moore, LCdr Kenneth, 237
Moores, James G., 132, 239, 247-8, 252, 254, *255*, 256
Morrison, Dr John, 84, 248, *249*, 250, 252
Mountbatten, Lord Louis, *28*
Munk, Dr Walter H., 107, 229, 235
Myllymaki, Ronald A., 248, 252

N

Nasmyth, Dr Patrick W., 3, *9*, 10-11, 15-7, 23, 27, 51, 141, 221
Nelson, J. Bradley, 93, 121-2
Nelson, F.D.H., 1
Nelson, Simon, 243

Nikiforuk, Thomas P., 247

O

O'Malia, John A., 143, *144*, 146, *147*, *150*, 161, 167, 171, *175*, *177*, 181, 184, *185*, 243-5, 247
Owen, Gwyn, 237
Ozard, Dr John M., 89, 101, 113-4

P

Parker, John W., 215
Pastro, Anthony E., 212, *225*, 229-30, 235
Patterson, Dr Ashton M., *29*, *37*, 59, 84, *100*, 213
Peebles, Kenneth, *115*
Pelletier, Dr Bernard, 197, 199-201, 203
Perron, Yvon, 168-70
Peters, Dr B. Frank, 15, 17, *30*, 75-6, 83-4, 101, *103*, *137*, 237, 242-7, 249, *250*, 254, *255*
Phillips, Capt John B., 114
Pickard, Dr George L., 10
Pierson, Capt (N), *19*
Poeckert, Dr Roland H., 125, *131*
Pounder, Dr Elton R., 143, *144*, 147, 156
Preston, Dr Jon M., 125, *126*, *131*

Q

Quartermain, Leslie, *41*

R

Raoux, Maj Raymond A., 248
Ray, Dr Carlton, 197-201
Rayner, Adm, *30*
Reesor, Dr J. Brian, *78*
Reid, Laurie, *102*
Religa, Richard J., 124
Rempel, Laura, 231, *234*
Robson, Robbie G., 156, 158, *159*, 163, *169*
Rodger, Robert J., 114
Roots, Frederick, 149, 151, 154, 160, 164, 166-7, 182, 188
Rowe, Frank, *30*
Rowland, Robert D., 247, 256
Rowsome, Mark S., *131*
Russel, Alan J., 83, 136, 248-9, 251, 254

S

Sanders, Dr Frederick H., 3, *7*, *9*, 12, 27, *31*, 46, *56*, 174, 191, 237
Schaefer, Donald, 237
Schattschneider, George K., 123, 132, 248, 254-5
Schmitz, Murdock E., 55, 247, 256
Schneider, Douglas, W., *135*
Schofield, Dr Derek, *78*, *104*, *249*
Schofield, Jane, 237
Scrimger, Dr Joseph A., 22, *30*, 34-5, 50, 108
Selkirk, Earl of, *29*
Sewell, Richard B.H., 17, 45, *46*, *74-75*, 152, 237, 241-2
Shand, J. Arthur, 17, *26*, 27, 39, 222
Shore, Dr George, *141*
Siddon, Dr Thomas, *103*, *137*
Silver, Edward, *30*
Simpson, Adelaide, 3
Simpson, George C., *41*
Singh, Amarpal, *102*
Smith, John D., 59, 79, 84, 89, *100*, 220-1, *225*, 228, *239*, *260*
Solandt, Dr Omand M., 5, *13*
Sotirin, Barbara, *116*, *119*
Stalinski, Dr J.P., 143, *144*, 147
Stanfield, Hon Robert, *74*
Stanners, Laurance C., *102*
Stavely, Sir William, *250*
Stewart, Dr Robert W., 6, 11, 15, *16*, 17, 212-3, 225
Stone, Joanne E., *102*
Street, David S., 171, 178
Street, Dr Kenneth N., 76, 83, *136*, 248-52, *249*, 254
Stringer, Joan, 252
Sturrock, William R., 76, 84, *136*, 248-50, 252
Syck, James, 107

T

Taylor, Steven H., 114, *120*
Temple, Ralph H., *30*, 237, *238*
Thomson, David J., 64, 104, *105*, 107
Thorleifson, Jon M., 59, 61, *63*, 109, 114, *115*
Tigg, Raymond, 235
Tooke, Captain, 156-7, 191-203
Toole, Capt Stanley, 208
Tully, Dr John P., 1, 4, 8, *19*, 34
Turner, Dr R. Glenn, 50, *63*, 84, *85*, *100*, 103
Tweedhope, Donald S.G., *30*, 219, 237, *238*, 246-7

U

Ujimoto, Capt Kenneth K., 114

V

Van Der Pryt, Capt Richard W., 114
Verrall, Dr Ronald I., 81, 109, 112, 114, *119*
Vincent, Gerry, 237
Vogel, Dr William M., 15, 125, *131*, 220

W

Waggoner, Clinton A., 17, 55, 75-6, 83, 139, 237, *242*, 247, 249-50
Wall, Warren, 205
Walton, David, *30*
Warren, Donald F., *99*
Waterman, James, 212
Watson, Sgt Robert W., 248
Weaver, Dr John T., 44
Weir, Robert C., 212
Westwood, Dr Evan K., 107
Wilmut, Dr Michael J., 236
Wilson, Dr Harold S., 94, 122-3,
Wilson, John A.F., 66, 232, 235
Wilson, M., 197
Wright, Sir Charles, 23, 24, 27, *30*, *39*, 40-2, *41*, *42*, *48*, 59
Wright, Patricia F., 24

Y

Yee, Lanny K., 237, 242, *243*
Yeremy, Maureen L., 114, *119*
Yeung, Keith K., 15, 91, *92*
Young, Dr Lawrence, 214

Z

Zachariason, Dr Frederick, 235
Zakarauskas, Dr Pierre, 112
Zhai, Dr Zhenhou, 250, 254
Zimmerman, Dr A. Hartley, 31, *32*, *48*, 148
Zimmerman, Mrs A.H., *32*

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